# Potential Use of Wildflower Species for Landfill Restoration in Southwestern Virginia

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ADDITIONAL INDEX WORDS. revegetation

**SUMMARY. Landfills are subject to public scrutiny because of potential environmental hazards, low aesthetic value, and rising costs of regulations governing landfill operation. In southwestern Virginia, landfill operators commonly seed landfills with nonnative perennial forbs and grasses. Our goal was to determine if wildflowers were a feasible alternative to the standard revegetation mixture. A standard landfill revegetation mixture and a wildflower mixture were sown at a landfill in Spring 1993 and were evaluated after one growing season. The number of species established in the wildflower mixture subplots was greater than in the standard mixture subplots, whereas cover of the two mixtures did not differ significantly. *Rudbeckia hirta*, *Coreopsis lanceolata*, *Coreopsis tinctoria*, and *Hesperis matronalis* thrived. *Lespedeza cuneata* was a confounding factor in determining cover estimates. Results of our study suggest that several native and naturalized species have potential for landfill restoration.**

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Landfills have been located away from public view; however, today they may be an integral part of community landscapes and are carefully evaluated for their aesthetic and financial impact after being sealed with a soil layer. Most states now require vegetation establishment over the soil liner as the initial step in stabilizing the landfill's contents. If the desired outcome for postclosure landfill use is a park or nature area, as is becoming increasingly common (Booth, 1990; Kissida and Beaton, 1991), then ecological, financial, and social concerns influence the choice of plants used for revegetation.

Many ecological factors reduce plant survival, including landfill gases, leachate emissions (liquid byproducts of landfill decomposition processes), and a highly altered and unstable habitat (Booth, 1990; Chan et al., 1991; Duell et al., 1986; Wong, 1988). Financial constraints also contribute to the choice of plant species because of variable seed costs and the amount of seed necessary to ensure high stand densities. Finally, social perceptions can shape the types of plants used; for instance, the public may prefer familiar nonnative species rather than unfamiliar native species.

Typically, a mixture of nonnative grasses and legumes is used for revegetation because of the known ability of these species to colonize waste and droughty areas, the low cost of their seeds, and their minimal maintenance requirements following germination. However, this standard revegetation mixture may reduce plant diversity by inhibiting colonization of native species. In addition, standard revegetation species have not been designed to provide an aesthetic display for the public and may not foster visitation by local birds, butterflies, or other fauna.

Alternatives to standard mixtures have been investigated; however, most of the research involves establishment of native trees on landfills (Gilman et al., 1985). Other types of plant communities, especially wildflower meadows and native grasslands, have received less attention. These plant species benefit native wildlife (Brown et al., 1984; Davis, 1989; Robinson and Handel, 1993; Smith, 1994), are often aesthetically pleasing, and facilitate invasion of native successional species (Brenner et al., 1984; Burger and Torbert, 1990; Robinson and Handel, 1993).

The goal of this study was to determine if a wildflower mixture could provide comparable floristic diversity and vegetative cover to a standard mixture at a landfill in southwestern Virginia.

## Methods and materials

**SITE DESCRIPTION.** The old Roanoke Regional Landfill covers 265 acres (107 ha) in Roanoke County, Va. The predisturbance vegetation of this area is of mixed *Quercus*, *Carya*, and *Acer* hardwood forest. The landfill was built up in layers as each mound of trash was contoured with soil, and slopes with bench terraces were created to stabilize the soil. Soils range in texture from clay to sandy clay to sandy clay loam. After each slope and bench terrace was completed, the area was hydroseeded with a standard mixture of nonnative grasses and legumes. Nitrogen, phosphorus, potassium, and calcium were added to hydroseed slurries. The oldest slopes at the base of the hill had vegetation ranging from 7 to 10 years old. The upper slopes were most recently contoured and seeded in May 1994.

**SEED SELECTION AND PREPARATION.** The wildflower mixture list included recommended native and naturalized wildflowers and grasses that were reported to be adapted well to stressful landfill conditions, such as low nutrient soils and high temperatures (Harvill et al., 1992; Radford et al., 1968; Wofford, 1989). The preliminary native species list was reduced to seeds available from several wildflower seed companies in the United States (Table 1). The standard mixture consisted of species commonly used at the Roanoke Regional Landfill (Table 1).

**SITE PREPARATION.** In March 1993, two 10 × 5-m plots were marked on each of five aspects on the active section of the landfill: northwest (NW), northeast (NE), north (N), west–northwest (W–NW), and southwest (SW). One plot in each pair was located on an upper more recently vegetated slope and the second was located on a lower slope with vegetation estimated at 4 to 8 years of age according to the landfill operator's records. Two 9-m$^2$ subplots were marked in each plot, with a space of 0.5 m separating the two subplots. Permanent quadrats of 1 m$^2$ were staked at the center of each 9-m² subplot for species richness and cover surveys.

Vegetation present in plots at the beginning of the study was not documented quantitatively, but was noted qualitatively as predominantly *Coronilla varia* and *Lespedeza cuneata* on the lower slopes, with more grasses on the upper slopes, particularly *Festuca arundinacea* and *Lolium perenne*. *Coronilla varia* dominated on the slopes on the southwestern aspect, whereas *Lespedeza cuneata* was more abundant on plots with other aspects.

To eradicate the preexisting vegetation, plots were sprayed in April 1993 with the broad-spectrum contact herbicide glyphosate (0.5% solution) (Monsanto). Each plot was sprayed twice, with an interval of 7 to 10 days between sprayings. More than 99% of the vegetation died within 14 days of spraying. The areas were raked lightly to remove plant debris. Soil was not tilled before hydroseeding to duplicate seedbed preparation used by the landfill operator.

In May, each 9-m² subplot was seeded with either the wildflower or standard mixture at a rate of 120 seeds/ft² (1292 seeds/m²), a rate recommended by wildflower seed companies and restoration practitioners (Shirley 1994). In each mixture, the number of seeds of each species was approximately equal.

The plots were not prepared with fertilizers or irrigated. The seed mixtures were mixed with 500 g of coarse construction sand and were spread by hand broadcasting so that each 9-m² subplot had an even distribution of the sand and seed. After an initial seeding on 8 May, a thunderstorm washed away the seeds. To ensure an adequate stand of vegetation for the landfill operator, all plots were reseeded on 10 June.

The plots were monitored weekly from 10 June until late August 1993. On each sampling date, total percent cover and percent cover of individual species were recorded in the 1-m² quadrat. In addition, all species present in the 9-m² subplots were recorded. Cover was measured by estimating the amount of green cover as a percentage of the total area of the 1-m² quadrat. Cover estimates for the final sampling date (20 Aug.) are reported, as this was the date on which the maximum cover was recorded.

Species richness is defined here as the total number of species recorded from observations in the 1-m² quadrats in each year. Species richness values are cumulative for all eight sampling dates.

Despite extensive efforts to kill prior vegetation with herbicides, *Lespedeza cuneata* and other species sprouted in the plots. Therefore, separate cover estimates are reported for *Lespedeza cuneata*, planted species besides *Lespedeza cuneata*, and colonizing/reemerging species besides *Lespedeza cuneata*. Species naturally colonizing plots and those that may have regrown from prior seeding were combined, as it was impossible to identify their source.

**Table 1. Origin and seed source for species seeded on experimental plots at the Roanoke, Va., Regional Landfill.**

| Species | Common name | Origin[z] | Seed source |
|---|---|---|---|
| | | Wildflower mixture | |
| *Andropogon gerardii* Vitm. | Big bluestem | MW | Prairie Nursery[y] |
| *Aster novae-angliae* L. | New England aster | MW | Applewood[x] |
| *Centaurea cyanus* L. | Cornflower | Europe | Lofts[w] |
| *Coreopsis lanceolata* L. | Lance-leaved coreopsis | MW | Lofts |
| *Coreopsis tinctoria* Nutt. | Plains coreopsis | MW | Applewood |
| *Echinacea purpurea* Moench. | Purple coneflower | MW | Applewood |
| *Helianthus annuus* L. | Annual sunflower | MW | Applewood |
| *Hesperis matronalis* L. | Dame's rocket | Pakistan | Lofts |
| *Liatris spicata* Willd. | Blazing star | MW | Applewood |
| *Lupinis perennis* L. | Perennial lupine | MW | Lofts |
| *Oenothera speciosa* Nutt. | Showy evening primrose | MW | S&S Seeds[v] |
| *Rudbeckia hirta* L. | Black-eyed Susan | SE | Lofts |
| *Schizachrium scoparium* Michx. | Little bluestem | MW | Prairie Nursery |
| *Silene armeria* L. | Catchfly | NE | Applewood |
| *Solidago rigida* L. | Stiff goldenrod | MW | S&S Seeds |
| | | Standard mixture | |
| *Agrostis alba* L. | Red top | Europe | Landscape Supply[u] |
| *Coronilla varia* L. | Crown vetch | Europe | Landscape Supply |
| *Festuca arundinacea* Schreb. | Kentucky 31-tall fescue | Hybrid | Landscape Supply |
| *Lespedeza cuneata* G. Don. | Sericea lespedeza | Hybrid | Landscape Supply |
| *Lolium multiflorum* Lam. | Annual rye | Europe | Landscape Supply |
| *Lolium perenne* L. | Perennial rye | Europe | Landscape Supply |
| *Secale cereale* L. | Abruzzi rye | Europe | Landscape Supply |
| *Setaria italica* Beauv. | German foxtail millet | Europe | Landscape Supply |
| *Trifolium pratense* L. | Red clover | Europe | Landscape Supply |

[z]MW = midwestern, NE = northeastern, and SE = southeastern United States.
[y]Prairie Nursery, P.O. Box 306, Westfield, WI 53964.
[x]Applewood Seed Co., 5380 Vivian St., Arvada, CO 80002.
[w]Loft's Seeds, 11417 Somerset Ave., Beltsville, MD 20705.
[v]S&S Seeds, P.O. Box 1275, Carpenteria, CA 93013.
[u]Landscape Supply, P.O. Box 12706, Roanoke, VA 24027.

Table 2. Characteristics of capping material soil at Roanoke Regional Landfill.

| Soil parameter | Mean ± SE |
|---|---|
| pH | 6.4 ± 0.7 |
| Organic matter (%) | 1.1 ± 0.4 |
| Soluble salts ($mg \cdot kg^{-1}$) | ---[z] |
| $NO_3$-N ($mg \cdot kg^{-1}$) | 7.7 ± 8.9 |
| P ($mg \cdot kg^{-1}$) | 24.0 ± 13.8 |
| K ($mg \cdot kg^{-1}$) | 93.1 ± 28.6 |
| Ca ($mg \cdot kg^{-1}$) | 594.0 ± 181.6 |

[z]In 1993, soluble salt concentrations were below detectable levels (<1 $mg \cdot kg^{-1}$) for all except the two southwestern plots, which were 166 and 128 $mg \cdot kg^{-1}$.

**SOIL ANALYSES**. In May 1993, 50-g samples of soil were taken from each experimental plot after spraying and before planting. Soil was sampled from the top 9 cm of six randomly selected sections within the 9-$m^2$ plot. Soils were analyzed at the Virginia Tech Soil Testing Laboratory using standard methods (Donahue, 1994). Organic matter was determined using the Walkley Black method. Nitrate nitrogen was extracted with $CuSO_4$, and concentrations were determined with an ion analyzer equipped with a nitrate-specific ion electrode assembly. Phosphorus, potassium, and calcium concentrations were determined using an inductively coupled plasma spectrometer.

## Results

Soil nutrients ($NO_3$ N, P, Ca, Mg, and K) and organic matter were generally low for soils of this region (Table 2). Soil nutrient levels, in particular $NO_3$ N and soluble salts, were highly variable across plots; this is typical of landfill soils, as the different soil horizons are mixed during the capping process (W.L. Daniels, personal communication).

Total rainfall during the study period was 122 mm, which is 165 mm below normal (National Oceanic and Atmospheric Administration, 1993). Mean temperature was 24.6 °C, which was 1.3 °C above normal (National Oceanic and Atmospheric Administration, 1993).

Eleven of the fourteen species of wildflowers seeded established on the 9-$m^2$ subplots on the landfill (Table 3). The most frequently occurring species were *Rudbeckia hirta*, *Coreopsis lanceolata*, and *Coreopsis tinctoria*; and two species that occurred least frequently were *Schizachrium scoparium* and *Solidago rigida*. *Setaria italica*, *Lolium multiflorum*, and *Coronilla varia* from the standard mixture were observed on most of the standard subplots. Total species richness and planted species richness were significantly higher in the wildflower than the standard subplots (Table 4).

Table 3. Total occurrence of each species.[z]

| Species name | Wildflower subplots (no.) | Standard subplots (no.) |
|---|---|---|
| | Wildflower mixture | |
| *Andropogon gerardii* Vitm. | 2 | 0 |
| *Aster novae-angliae* L. | 0 | 0 |
| *Centaurea cyanus* L. | 8 | 0 |
| *Coreopsis lanceolata* L. | 8 | 0 |
| *Coreopsis tinctoria* Nutt. | 9 | 0 |
| *Echinacea purpurea* L. | 8 | 0 |
| *Helianthus annuus* L. | 6 | 0 |
| *Hesperis matronalis* L. | 5 | 0 |
| *Liatris spicata* Willd. | 0 | 0 |
| *Lupinus perennis* L. | 2 | 0 |
| *Oenothera speciosa* Nutt. | 6 | 0 |
| *Rudbeckia hirta* L. | 8 | 0 |
| *Schizachrium scoparium* Michx. | 0 | 0 |
| *Silene armeria* L. | 7 | 0 |
| *Solidago rigida* L. | 3 | 0 |
| | Standard mixture | |
| *Agrostis alba* L. | 0 | 2 |
| *Coronilla varia* L. | 4 | 6 |
| *Festuca arundinacea* Schreb. | 0 | 1 |
| *Lespedeza cuneata* G. Don. | 10 | 10 |
| *Lolium multiflorum* Lam. | 0 | 4 |
| *Lolium perenne* L. | 0 | 0 |
| *Secale cereale* L. | 0 | 2 |
| *Setaria italica* Beauv. | 3 | 9 |
| *Trifolium* sp. | 2 | 4 |
| Colonizing species | | |
| *Ambrosia artemisiifolia* L. | 2 | 2 |
| *Digitaria* sp. | 6 | 8 |
| *Erigeron* spp. | 2 | 0 |
| *Lathyrus sylvestris* L. | 2 | 2 |
| *Liriodendron tulipifera* L. | 5 | 1 |
| *Polygonum pensylvanicum* L. | 4 | 4 |
| *Rumex* sp. | 2 | 2 |
| *Toxicodendron radicans* L. | 0 | 1 |
| Total number of species recorded | 24 | 15 |

[z]Values are the number of subplots out of a total of 10 on which each species was recorded.

Mean planted cover for both mixtures was variable and low (Table 4). Percent planted cover was not significantly different between the wildflower and the standard mixtures. Total cover was significantly higher in standard mixture plots, which was primarily due to higher cover by *Lespedeza cuneata* (Table 4).

## Discussion

A few nonnative grass and legume species are commonly used to revegetate landfills because they are considered to be better adapted to the stressful conditions, including compacted, poorly drained soils, often toxic gas emissions, and elevated air and soil temperatures (Duell, 1988; Flower et al., 1981). However, results of this

**Table 4. Number of species and percent cover for wildflower and standard mixture quadrats.**[z]

| Parameter | Wildflower | Standard | Significance[y] |
|---|---|---|---|
| | | Species richness | |
| Planted | 5.9 ± 3.0 | 1.8 ± 1.0 | ** |
| C/R[x] | 2.7 ± 1.6 | 2.6 ± 1.3 | NS |
| Total[v] | 9.6 ± 3.6 | 5.2 ± 2.0 | ** |
| | | Cover | |
| Planted | 4.7 ± 4.6 | 3.5 ± 5.0 | NS |
| C/R | 15.2 ± 11.2 | 20.6 ± 17.8 | NS |
| *Lespedeza cuneata* | 11.0 ± 13.1 | 26.2 ± 22.5 | NS |
| Total | 30.8 ± 13.2 | 50.2 ± 17.0 | * |

[z]Values are means ± SE.
[y]Data were analyzed using a *t* test.
[x]C/R = Colonizing and reemerging species.
[v]Total species richness includes planted species richness, C/R species richness, and *Lespedeza cuneata*. *Lespedeza cuneata* was not included in planted or C/R species richness because of the impossibility of determining its source.
NS,*,**Significant at $P < 0.05$ or 0.01, respectively, for differences in mixture across slope and aspect.

and other studies (Davis and Coppeard, 1989; Sabre et al., in press; Wong, 1988) suggest that several wildflower species have potential for landfill revegetation. In Great Britain, 17 of 21 species of wildflowers seeded on a landfill became established (Davis and Coppeard, 1989).

In our study, 78% of the wildflower species became established on the landfill. A few species, such as *Centaurea cyanus*, *Coreopsis lanceolata*, and *Rudbeckia hirta* show particular promise for revegetating disturbed areas. Species richness was higher in areas seeded with the wildflower mixture; however, more wildflower species were seeded. While total vegetation cover was higher on subplots seeded with the standard mixture, some of this cover resulted from regrowth of vegetation seeded previously; when planted cover values were compared, the differences were not significant.

The low and variable cover (0.5% to 15%) of the seeded wildflowers can be explained in several ways. First, the seeding rates used, which were recommended by the wildflower seed companies and restoration practitioners (45 to 75 lb/acre), were much lower than the 100 lb/acre commonly planted by landfill operators. Second, the warm and dry conditions in Virginia during Summer 1993 likely inhibited seed germination and seedling survival and growth. Third, several of the wildflower species tested may not be well adapted to the exceptionally poor soil conditions. Finally, growth of wildflower species may have been inhibited by the regrowth of previous vegetation.

While the results of this study suggest that several wildflower species have potential for landfill revegetation, some constraints were imposed by the landfill regulations, which complicate interpretation of the results and necessitate further research on the suitability of these species. As discussed previously, location of experimental plots was limited to areas that had already been revegetated. Differences in previous vegetation, particularly dense stands of *Coronilla varia* (a nitrogen-fixing species) in the southwestern plots may have been the cause of highly elevated nitrogen levels in these plots.

Concern about disturbance of existing vegetation was another constraint on this study. The number and size of experimental plots, which resulted in low replication of experimental treatments, were limited by the landfill operator. Finally, due to changes in landfill regulations in Virginia, the landfill was recapped in Summer 1994, thereby terminating the study. Such regulatory interventions are not uncommon in restoration projects, and their occurrence illustrates a common challenge facing restoration practitioners.

Using wildflowers for landfill revegetation is currently limited by concern of their low establishment rates and the high cost of purchasing seeds. Our research demonstrates the importance of testing revegetation protocols in small plots before landfill closure; these experiments serve to select species that are most likely to become established and identify potential problems.

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# Quantifying the Effect of Plug-flat Color on Medium-surface Temperatures

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**ADDITIONAL INDEX WORDS.** solar radiation, longwave radiation, evaporation

**SUMMARY. Medium-surface temperature of black, gray, and white plug sheets was measured with thermocouples and an infrared camera. During the night, there were no medium-surface temperature differences between the plug flats; however, medium-surface temperature was 2 to 3 °C below air temperature. Medium-surface temperature increased as solar radiation (280 to 3000 nm) increased. About 80 W of solar radiation/m² was incident on the plug-flat surface before medium-surface temperature equaled air temperature. Medium-surface temperature in the black, gray, and white flats was 6.3, 6.1, and 5.3 °C above air temperature, respectively, when 300 W of solar radiation/m² (30% of the maximum solar radiation during the summer) was incident on the medium surface. Thus, incident solar radiation has a greater effect on medium surface temperature than plug-flat color.**

Commercial bedding plant growers typically germinate seeds in plug sheets designed with 128 to 800 cells/flat (800 to 5000 plants/m²) (Karlovich and Koranski, 1994). Although most seeds are germinated on top of the medium surface, germination percentage of some species is improved by covering the seeds with a fine coating (1 to 2 mm) of a material such as vermiculite. After seeds are sown, the plug flats are placed into either a germination chamber or the greenhouse.

Temperature is a critical factor influencing seed germination (Carpenter, 1994). Whenever seed temperatures are not optimum, germination will be delayed or its percentage will decrease. The temperature of the germinating seed is influenced primarily by the medium-surface temperature, which is affected by many variables, including plug-flat color. Plug-flat color influences the amount of solar radiation absorbed. Black plug flats most commonly are used by commercial growers, although white plug flats are used during the summer to prevent excessively high temperatures. Soil temperatures are often excessive during container-grown plant production in periods of high solar radiation (Martin and Ingram, 1992).

We are unaware of any data showing the influence of plug-flat color on medium temperature. The objective of this project was to quantify the effect of plug-flat color on medium-surface temperature under different irradiance conditions.

## Materials and methods

White, gray, and black 406-cell plug flats obtained from a commercial grower (Blackmore Co., Inc., Belleville, Mich.) were filled with a peat-based medium. The flats were placed on a solid aluminum subirrigation bench in a greenhouse with air maintained at 25 °C, the optimum temperature for germination of many bedding plant species (Karlovich and Koranski, 1994). The medium was kept moist for the duration of the experiment, which was conducted over a 10-day period in a glass greenhouse in July 1993.

The medium-surface temperature in the center of nine randomly chosen plug cells (three per plug-flat color treatment) was measured with 80-µm-diameter fine-wire thermocouples. The thermocouples were inserted into the top 1 mm of media and in the center of the plug cell. The measurement variation between the thermocouples was about ±0.15 °C. A pyranometer (Eppley Laboratory, Inc., Newport, R.I.) was used to measure solar radia-

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