Research into the Development of Biological Methods of Dust Suppression in the Antelope Valley

2006 Final Report

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DISCLAIMER

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1.0 ABSTRACT

Antelope Valley, located fifty miles north of Los Angeles in the Mojave Desert, has been experiencing air quality problems caused by frequent dust storms. Bordered to the south by the San Gabriel Mountains, to the west by Coastal Mountain Ranges and to the northwest by the Tehachapi Mountains, Antelope Valley was intensely farmed until 10 to 20 years ago. Increased water costs caused many farmers to abandon farming, leaving vast tracts of bare, disturbed land. The air pollution problem caused by the abandonment of farms, miles of dirt roads, increased construction, summer brushfires and other human disturbances, combined with high winds, has led to high levels of PM_{10} in and around Lancaster and Palmdale. A resurgence of farming in Antelope Valley has been seen over the last few years. Most of the land used during the farming season is left fallow for up to three years because of pathogens in the soil from root crops. This practice introduces additional airborne dust into an already existing air problem. The Dustbusters, comprised of a coalition of local farmers, the Antelope Valley Resources Conservation District, the California Air Resources Board, South Coast Air Quality Management, the United States Department of Agriculture, the Natural Resource Conservation Service, the City of Los Angeles Department of World Airports, and Southern California Edison, invited the Soil Ecology and Restoration Group (SERG) of San Diego State University to join them in addressing issues of dust mitigation in Antelope Valley.

2.0 EXECUTIVE SUMMARY

Agreement # 01-339 gave SERG the task of researching cost efficient methods of revegetating abandoned farmland with native plant species. The goal of this project is to suppress airborne particulate matter and restore the soil to a point where native plant communities can be reestablished. The process of reestablishing such native plant communities in arid and semi-arid areas is hampered by the physical impacts caused by human activities. These activities (including farming, off-road vehicle use and construction) impact the soil through compaction, loss of soil microbes, and changes in soil nutrient levels. The role of SERG is to determine the specific soil impacts, develop the most cost-effective methods to mitigate these impacts, recognize the native species best suited for restoration on such disturbed lands, and establish how best to reestablish a self-sufficient plant community. In June of 1998, two sites were selected for experimental plots and an undisturbed site was selected for reference data. The first experimental site is located on the northern end of 50th Street East and the second is on 90th Street East near E Avenue O. The 50th Street site was selected to represent recently abandoned farmland and the 90th Street site was selected to represent farmland that had been fallow for many years. An undisturbed reference site is located at 90th Street and Avenue K, where soil samples were consistently collected from under the same Joshua tree. In 2000, new information stating that the 50th Street site had not been farmed for many years, but had been regularly flooded with secondary effluent, caused the Dustbusters to abandon the 50th Street site and replace it with a site that had been farmed recently. This decision was made because the secondary effluent had dramatically increased the soil nutrient levels, compared to those usually found on farmland, and therefore the site is not typical of recently abandoned farmland. A new site, donated by Phillip Giba, of Giba farms, was farmed as recently as the 2002 season. Located on 85th Street, in Lancaster, the new site was planted in the winter of 2002.

Research on the 90th Street site was concluded in 2004. Final data and discussion on that section of the project was reported in the 2004 Annual Report. This report gives an overview of the entire project, including site preparation, planting, maintenance and monitoring methods followed by a detailed account of all activities and data collected at the 85th Street site from July 2005 through July 2006.

3.0 METHODS

3.1 Site Preparation

Los Angeles World Airports (LAWA) provided the original two sites for SERG to conduct revegetation experiments. The first site, located on 50th Street East and Avenue N-8, was thought to be abandoned farmland that had been farmed as recently as 1995. Information provided by Jim Bort, from LAWA, stated that the site had lain fallow for twenty-five years. The site had, however, been used by the Los Angeles County Sanitation District for the disposal of secondary effluent as recently as 1997. The furrows, originally believed to be evidence of recent crop activity, were actually used to divert the secondary effluent evenly over the fields. The replacement site, located on 85th Street East and Avenue F, was used for growing onions as recently as 2002, according to the owner of the land, Mr. Phil Giba. The second site, located on 90th Street East and Avenue O-8, appeared to have been abandoned at least fifteen to twenty years ago. The 50th Street site was dominated by scattered groups of non-native annual grasses and *Salsola tragus* (Russian thistle). By visual and physical inspection of the soil, it was determined to be compacted, probably due to the recent furrowing activity. The 90th Street site showed no signs of furrowing and was lightly covered with non-native annual grasses, *Salsola tragus* (Russian thistle), and a few native species, including the early seral invader *Chrysothamnus nauseosus* (rubber rabbitbrush). The soil at the 90th Street site was also compacted. Due to recent agricultural activities, the 85th Street site showed no signs of growth in the late summer/early fall of 2002, and the soil was determined to be compacted.

On November 25, 1998, SERG personnel outlined 15 m x 30 m shrub plots and 30 m x 30 m windbreaks at both the 50th Street site and the 90th Street site. The Palmdale Regional Airport supplied a John Deer tractor that was used to back blade all of the plots, knock down existing vegetation, and construct windbreaks. Non-native vegetation knocked down on site was incorporated into the 1 m tall by 10 m long windbreaks to provide stabilization and organic matter to the soil. The tractor was again used in December 1998 to alleviate soil compaction. The tractor attachment had 45 cm ripping bars that loosened the soil in all plots to a depth of 30 cm and incorporated dead, non-native, plant material into the soil to provide additional organic matter.

In January 1999, SERG personnel installed perforated irrigation pipe into the windbreak mounds at both the 50th Street and 90th Street sites. All plants were outplanted in January and provided with TreePee™ or Tubex™ plant protectors to reduce herbivory. In addition, each shrub plot was provided with soil amendments and irrigation treatments as required by the experimental design described in the following section.

Once the decision was made to abandon the 50th Street site and replace it with a new site located on 85th Street, site preparation began. In September 2002, Giba Farms supplied a

John Deer 4450 tractor equipped with a back blade that was used to construct 24 windbreak mounds. Perforated irrigation pipe was installed for the designated windbreaks, and shrub plots were outlined. Preparations, planting, and set up of the experimental design was completed by SERG personnel in October and November of 2002. Shrubs were provided with TreePees™ as protection from herbivores.

3.2 Experimental Design

Two plot designs were employed; shrub plots (15 m x 30 m) and windbreak plots (30 m x 30 m). Shrub plots were established using variables numbering 2x3x5 with two types of irrigation methods (surface watering or deep-pipe), three types of surface applied soil amendments (Scotts Earthgro® western bark nuggets wood chips, Kellogg Gromulch®, and control), and five plant species (Figure 1).

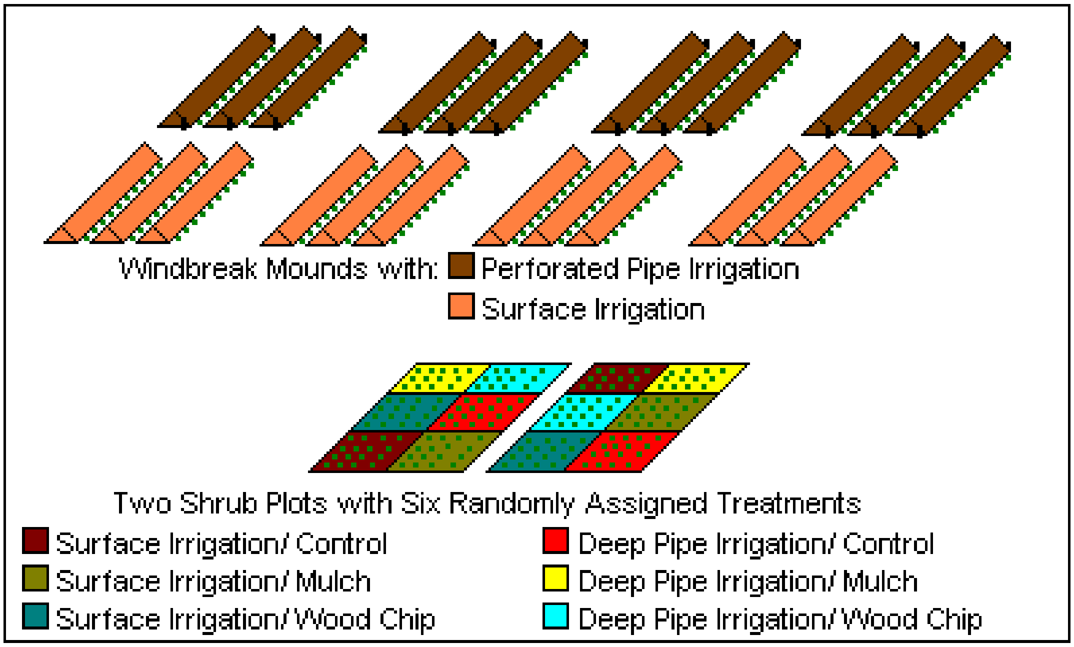


Figure 1. Experimental plot design and layout

Irrigation and soil amendment variables and the five plant species selected were displayed as Table 1. All treatments were randomly assigned within a plot, with each of the sites having two shrub plots. Each shrub plot at the 50th Street site and the 90th Street site was planted with 160 seedlings, and each shrub plot at the 85th Street site was planted with 120 seedlings. The 50th Street site and the 90th Street site shrub plots were prepared to hold four soil amendments. Only three feasible soil amendments were conceived, and so the shrub plots on these sites were given two control amendment treatments. The 85th Street site was later prepared for three soil amendments, resulting in the difference in planting numbers. A total of 880 shrub plot seedlings were planted.

Table 1. Shrub Plot and Windbreak Plot Variables.

	Shrub Plot (2x3x5)	**Windbreak** (2x5)
Irrigation Method		
Surface	x	x
Deep-pipe	x	x
Soil Amendment		
Control	x	N/A
Mulch	x	N/A
Wood chip	x	N/A
Species		
Atriplex canescens	x	x
Atriplex lentiformis	x	x
Atriplex polycarpa	x	x
Larrea tridentata	x	x
Prosopis glandulosa	x	x

Shrub plot seedlings were installed either with a basin for surface irrigation or with deep-pipe for underground irrigation via an aboveground pipe. Basins were constructed to a height of 5-10 cm above ground level, with widths of approximately 0.5 m. The deep-pipe was constructed using 2-inch (in.) PVC pipe cut in 46-cm. sections and buried to a depth of 30 cm. Deep-pipe sections were installed during outplanting. They were positioned approximately 10 cm. from the bases of seedlings, with a slight angle towards the root ball (Figure 2). The above ground opening of deep-pipe sections were covered with netting to prevent clogging. Surface amendments were applied as a 5 cm. layer spreading 1 m. from the bases of seedlings. The design of shrub plots has been displayed in Figure 3. A snapshot of shrub plots at the 85th Street site was taken for Figure 4.

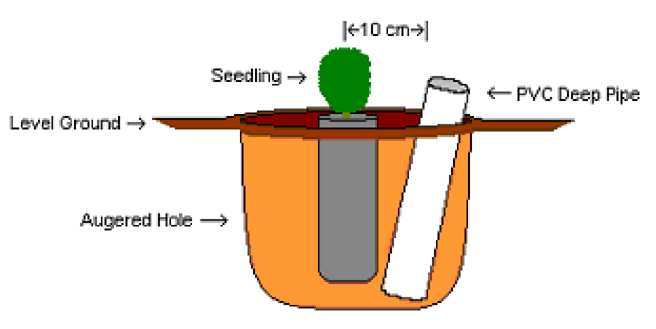


Figure 2. Deep-pipe placement in pre-augered planting hole

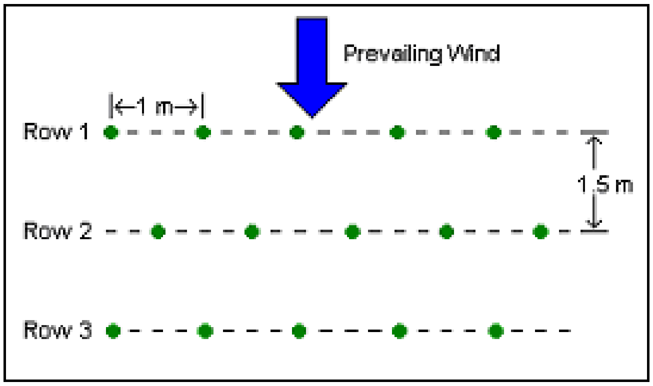


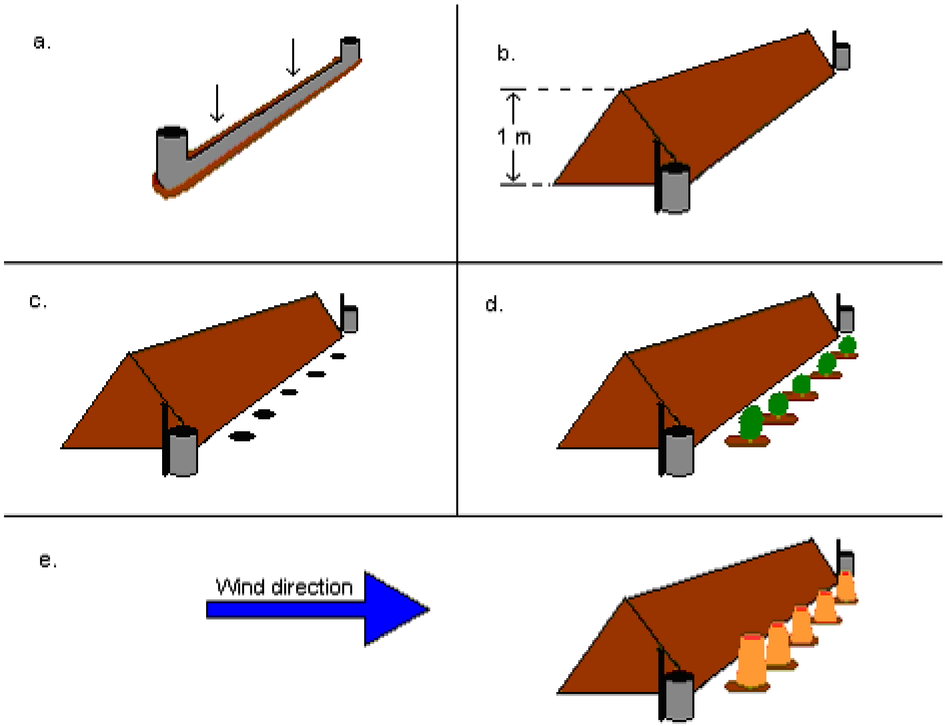
Figure 3. Shrub plot triangular planting scheme

Figure 4. Shrub plots at the 85th Street site, June 2004

Windbreak plots were established with variables numbering 2x5 (see Table 1) consisting of two irrigation treatments (perforated pipe irrigation and surface irrigation) and 16 individual plants per windbreak from each of the five native plant species selected. Each site was prepared with four windbreak plots and each plot was given six windbreaks, three with surface irrigation and three with perforated pipe irrigation.

Windbreak berms were arranged perpendicular to the direction of the strongest prevailing winds. Seedlings were planted on the lee side of windbreak berms. Windbreak plots were irrigated either by surface irrigation or by installed 4-inch perforated pipe. Each plant at surface irrigated windbreak plots was installed with a basin. Half-perforated, flexible polyethylene pipe with holes pre drilled on one side of the pipe were cut in 12-m.

sections to allow for 1 m. of exposed pipe on both ends of the 10-m. berms. Construction of windbreak plots irrigated with perforated pipe began by digging 30-45 cm. trenches to a length of 10 m. for the installation of perforated pipe. Perforated pipe was arranged in the trenches with drainage holes facing down, and attached to iron re-bar driven into the ground. Wherever surface irrigation was used, windbreak layout was marked with iron re-bar. A tractor equipped with a sharp angled back-blade was used to construct windbreak berms (Figure 5). The berms were pulled in a backwards direction by the back-blade. The soil relocated for the construction of windbreak berms was from downwind, and seedlings were installed on the lee side of windbreak berms following construction. SERG planted each windbreak with 16 seedlings for a total of 1,152 windbreak plot seedlings. A photograph of windbreak plots at the 85th Street site (Figure 6).



a. Insert perforated pipe into pre-dug trench. b. Fill the trench in and construct the windbreak mound. Attach protruding pipe to metal stake for support. c. Auger Seedling planting holes. Beware not to auger through the pipe. d. Plant seedlings and construct catchment basins. e. Place plant protectors.

Figure 5. Windbreak construction

Figure 6. Windbreaks at the 85th Street site, June 2004

3.3 Seed Collecting and Planting

The native plant seedlings used for this project were grown in the SERG greenhouse at San Diego State University. The seed, obtained from S&S Seeds, had been collected from the Mojave Desert in and around Antelope Valley. Plants for the 50th Street site and the 90th Street site were germinated in June 1998 and then transplanted to plant bands (5x5x20 cm and 8x8x25 cm). Seedlings were watered twice each week for the first three months and then on a weekly basis. Seedlings were fertilized for the first three months using half strength commercial fertilizer. In November 1998, the plants were transferred to a lathe house at the University of California, Riverside, to aid acclimation to desert conditions. Plants for the 85th Street site were germinated in April of 2002. Except for having been acclimated to desert conditions in San Diego rather than Riverside, methods for growing the 85th Street site plants were the same as methods for growing the 50th Street site plants and 90th Street site plants.

In January 1999, the 50th Street site and the 90th Street site were prepared for planting seven months after seeds were germinated. A power auger was used to dig holes and each hole was saturated with water prior to planting. Plant protectors (TreePees™) were used to protect the plants from herbivory. All plants were re-watered after planting. Seven hundred and four plants were put at each site: 320 on the shrub plots and 384 on the windbreaks. Irrigation methods were installed at this time. Perforated pipes were buried at a depth of 30 cm and ran the length of windbreaks. Evenly spaced holes in perforated pipe distributed water underground when the pipe was filled from the surface at either of the two ends that protrude above the ground. Deep-pipe sections were placed vertically into the ground and were buried at a depth of 30 cm for manual irrigation of individual plants. Surface irrigation basins were built for plants that did not have underground irrigation. The shrub plots were divided equally so that half of the plants had basins and half were provided with a PVC deep-pipe. Control, mulch or wood chip amendments were applied to shrub plot sections as designated.

In October and November of 2002, the 85th Street site was prepared for planting seven months after seeds were germinated. Six hundred and twenty-four seedlings were put on the site: 240 plants on the shrub plots and 384 on the windbreak plots.

3.4 Maintenance and Monitoring

Sites were monitored for plant survival and biomass, and soil was sampled for monitoring of microorganisms, macro- and micro-nutrients, organic matter, and pH level. Plants were monitored annually in June. Biomass monitoring indicated the annual volumetric growth of the plants. Procedure for biomass monitoring was measurement of individual plant height, width and depth. Soil samples were collected twice annually in March and October to form a timeline of biological, chemical and physical properties. A portion of each soil sample was sent away to A&L Laboratories, in Modesto CA, for nutrient, organic matter and pH level analysis. The remaining portion of the soil samples was analyzed by SERG for fungal and bacterial counts.

In March 1999, numerous plant protectors were blown off by high winds at the 90th Street site. Many of the unprotected seedlings suffered heavy herbivory damage and had to be replaced. Plant protectors were replaced on the remaining unprotected plants and secured with rebar. In March of 2000, 489 plants were planted at the 90th Street site to replace those that had been lost. Since there were only a limited number of the original species available at that time, other species were used as well. All replacement plants were grown from Mojave Desert seed at the San Diego State University SERG greenhouse (Table 2).

Table 2. Species Used to Replant the 90th Street Site.

Species	**Total**	**Species**	**Total**
Ambrosia dumosa (burro-weed)	1	*Hymenoclea salsola* (cheese bush)	5
Atriplex canescens (fourwing saltbush)	72	*Isomeris arborea* (bladderpod)	31
Atriplex lentiformis (big saltbush)	2	*Larrea tridentata* (creosote bush)	57
Atriplex polycarpa (allscale)	146	*Lycium andersonii* (Anderson wolfberry)	25
Ephedra nevadensis (green ephedra)	57	*Prosopis glandulosa* (honey mesquite)	82
Eriogonum fasciculatum (California buckwheat)	2	*Senna armata* (spiny senna)	9

All sites were irrigated according to the frequency illustrated in Table 3 until they reached mature size and became established. The 50th Street site was provided with supplemental water through July 2000. The 90th Street site, since it was replanted, continued to be watered until January 2001. Once established, both sites were able to survive without supplemental water. The 85th Street site was provided with supplemental water twice per month through February 2003. Starting at the end of February 2003, until February 2004, the plants were provided with supplemental irrigation once per month. Supplemental watering ended in March 2004 when plants became established. Had seasonal precipitation been above average, supplemental irrigation would have been less frequent. Under such conditions, supplemental irrigation may have saturated and harmed plants.

Table 3. Supplemental Irrigation Quantities and Intervals.

Months After Outplanting	Gallons of Water per Plant	Watering Interval
1-3	1	2 weeks
4-6	1/2	2-3 weeks
7-12	1/2	3-4 weeks

In July 2000, SERG personnel began removing plant protectors from the 50th Street site and the 90th Street site. Plant protectors were removed from plants when it was determined they were interfering with the natural morphology of the plant. The protectors were removed on a regular basis throughout the year, with all removed by June 2001. Based on the same criteria as with the two earlier sites, protectors were removed from the plants on the 85th Street site beginning April 2003 and ending February 2005.

Plant survival and biomass data was collected by surveying plots for percent survival data and measuring the height, length and width of surviving plants for biomass data, calculated in cubic meters (m^3). Soil samples were collected at the sites to monitor macro- and micro-nutrients, organic matter, pH level, and microorganisms. Sampling style involved scraping away the top layer of organic matter, digging a column 6-8 in. deep, and cutting a band of the cylinder to represent all levels of soil. Research site samples were taken from underneath the canopies of *Atriplex* species on the northwest sides. The recorded values from the Undisturbed site are averages of two samples taken at a radii of 6 in. and 12 in. from the trunk of the same Joshua tree each season. Samples were split into two portions: one portion was sent to A&L Laboratories for analysis of macro- and micro-nutrient, organic matter and pH levels, and the other portion was kept at SERG for Europium (III) staining and preparation of slides to be examined using a fluorescent microscope. Europium bound to sample DNA and fluoresced under UV light. The process was used to determine the ratio of bacteria to fungal hyphae per gram of soil. A shrub dominated habitat, such as those naturally found in the Mojave Desert, would be expected to have a fungal dominated mineralization cycle. Disturbed habitats, dominated by non-native annual species, would be expected to have a bacteria dominated mineralization cycle. By analyzing the ratio of bacteria to fungi, it was determined whether the disturbed mineralization cycles were on their way to being rehabilitated. Data derived from samples at all three sites, but particularly the 50th Street site and the 85th Street site, indicated that high nutrient levels support a bacteria dominated environment in the soils. After the soil sampling of spring 2003, SERG personnel determined that the slowly decreasing bacteria levels were still too high for soil fungal readings to provide much useful information. Fungal slides were last created and read in March 2003. Unless old agriculture land had been abandoned for over 10 years, SERG would recommend that analysis of fungal/bacteria levels not be conducted due to high residual levels of soil nutrients that would likely be found in the soil.

4.0 RESULTS

The species *Atriplex canescens*, *Atriplex lentiformis*, *Atriplex polycarpa*, *Larrea tridentata*, and *Prosopis glandulosa* were planted at both the 90th Street site and the 85th Street site. However, total survival and biomass data for the 90th Street site treatments include species not present at the 85th Street site (*Ambrosia dumosa*, *Ephedra nevadensis*, *Eriogonum fasciculatum*, *Hymenoclea salsola*, *Isomeris arborea*, *Lycium andersonii*, and *Senna armata*). These species all performed poorly and may have negatively skewed the 90th Street site total survival and biomass statistics in relation to the data for the shared species at the 85th Street site, where only *Atriplex canescens*, *Atriplex lentiformis*, *Atriplex polycarpa*, *Larrea tridentata*, and *Prosopis glandulosa* were planted. The final results listed for the 90th Street site were from 2004, and for the 85th Street site from 2006.

Data was listed first as survival percentages and average biomasses for species and treatments. To recommend species and treatments for revegetation, percent survival and average biomass data must both be analyzed. Survival percentages and average biomasses were weighted equally, and the product of the two resulted in performance values without units. A larger value means better performance. Performance values were calculated separately for the 90th Street site and the 85th Street site. These values were used to rank performances and to judge which species and treatments are most effective.

Some of the figures displayed from this point on have been summarized with linear trend lines, corresponding equations and R squared values. These summaries were all created with Microsoft Excel.

4.1 Survival, Biomass and Performance Values

4.1.1 90th Street Site

At the 90th Street site, *A. polycarpa* was the species with the highest survival percentages at both shrub plots (84%) and windbreak plots (88%). In the shrub plots, *A. lentiformis* had the second highest survival percentage (65%). At the windbreak plots, *A. canescens* had the second highest survival percentage (84%). *L. tridentata* and *P. glandulosa* had the lowest survival percentages at both shrub plots and windbreak plots (Table 4).

Table 4. 90th Street Site 2004 Species Survival Percentages.

Species	**Shrub plots**	**Windbreak plots**
A. canescens	61%	84%
A. lentiformis	65%	71%
A. polycarpa	84%	88%
L. tridentata	41%	68%
P. glandulosa	47%	65%
Total	50%	68%

The shrub plot treatment with the highest survival percentage was deep-pipe/control (61%). Second and third, respectively, were deep-pipe/mulch (58%) and surface/wood-chip (48%). At the windbreak plots, survival for perforated pipe irrigation (68%) was slightly higher than for surface irrigation (67%) (Table 5).

Table 5. 90th Street Site 2004 Treatment Survival Percentages.

Variable		**Survival**
Shrub plots	Surface/Control	42%
	Surface/Mulch	43%
	Surface/Wood chip	48%
	Deep-pipe/Control	61%
	Deep-pipe/Mulch	58%
	Deep-pipe/Wood chip	46%
Windbreak plots	Surface irrigation	67%
	Perforated pipe irrigation	68%

A. canescens was the species with the highest average biomass (3.03 m^3) at the shrub plots. *A. polycarpa* had the second highest average biomass (2.58 m^3) at the shrub plots. At the windbreak plots, *A. canescens* had the highest average biomass (4.02 m^3), and *A. polycarpa* had the second highest average biomass (1.86 m^3) (Table 6).

Table 6. 90th Street Site 2004 Species Average Biomasses (m^3).

Species	**Shrub plots**	**Windbreak plots**
A. canescens	3.03	4.02
A. lentiformis	1.30	1.12
A. polycarpa	2.58	1.86
L. tridentata	0.13	0.04
P. glandulosa	0.64	1.29
Total	1.71	1.98

The shrub plot treatment with the highest average biomass was surface/control (2.31 m^3). Second and third, respectively, were deep-pipe/wood chip (2.24 m^3) and surface/wood chip (2.08 m^3). At the windbreak plots, average biomass for perforated pipe irrigation (2.23 m^3) was higher than for surface irrigation (1.63 m^3) (Table 7).

Table 7. 90th Street Site 2004 Treatment Average Biomasses (m^3).

Variable		**Biomass**
Shrub plots	Surface/Control	2.31
	Surface/Mulch	0.55
	Surface/Wood chip	2.08
	Deep-pipe/Control	1.37
	Deep-pipe/Mulch	1.55
	Deep-pipe/Wood chip	2.24
Windbreak plots	Surface irrigation	1.63
	Perforated pipe irrigation	2.23

At the 90th Street site shrub plots, the species with the highest performance value was *A. polycarpa* (2.17), followed by *A. canescens* (1.85). The treatment with the highest performance value was deep-pipe/wood chips (1.03), followed by surface/wood chips (1.00) (Table 8).

Table 8. 90th Street Site 2004 Shrub Plot Performance Values.

Variable		**Performance**
Species	*A. canescens*	1.85
	A. lentiformis	0.85
	A. polycarpa	2.17
	L. tridentata	0.05
	P. Glandulosa	0.30
Treatment	Surface/Control	0.97
	Surface/Mulch	0.24
	Surface/Wood chips	1.00
	Deep-pipe/Control	0.84
	Deep-pipe/Mulch	0.90
	Deep-pipe/Wood chips	1.03

At the 90th Street site windbreak plots, the species with the highest performance value was *A. canescens* (3.38), followed by *A. polycarpa* (1.64). Perforated pipe irrigation (1.52) had a higher performance value than surface irrigation (1.09) (Table 9).

Table 9. 90th Street Site 2004 Windbreak Plot Performance Values.

Variable		**Performance**
Species	*A. canescens*	3.38
	A. lentiformis	0.80
	A. polycarpa	1.64
	L. tridentata	0.03
	P. Glandulosa	0.84
Treatment	Surface irrigation	1.09
	Perforated pipe irrigation	1.52

4.1.2 85th Street Site

At the 85th Street site, *A. lentiformis* was the species with the highest survival percentages at both shrub plots (85%) and windbreak plots (97%). *A. polycarpa* had the second highest survival percentage at both the shrub plots (79%) and at the windbreak plots (96%). *L. tridentata* and *P. glandulosa* had the lowest survival percentages at both shrub plots and windbreak plots (Table 10).

Table 10. 85th Street Site 2006 Species Survival Percentages.

Species	**Shrub plots**	**Windbreak plots**
A. canescens	74%	92%
A. lentiformis	85%	97%
A. polycarpa	79%	96%
L. tridentata	41%	41%
P. glandulosa	35%	31%
Total	67%	73%

The shrub plot treatment with the highest survival percentage was surface/mulch (75%). The treatment with the second highest survival percentage was surface/control (73%). The treatments deep-pipe/mulch and deep-pipe/wood chip were tied for third at 68% survival. At the windbreak plots, survival for perforated pipe irrigation (68%) was slightly higher than for surface irrigation (67%) (Table 11).

Table 11. 85th Street Site 2006 Treatment Survival Percentages.

Variable		**Survival**
Shrub plots	Surface/Control	73%
	Surface/Mulch	75%
	Surface/Wood chip	58%
	Deep-pipe/Control	60%
	Deep-pipe/Mulch	68%
	Deep-pipe/Wood chip	68%
Windbreak plots	Surface irrigation	73%
	Perforated pipe irrigation	73%

A. lentiformis was the species with the highest average biomass (4.07 m^3) at the shrub plots. *A. polycarpa* had the second highest average biomass (4.05 m^3) at the shrub plots. At the windbreak plots, *A. polycarpa* had the highest average biomass (3.55 m^3), *A. canescens* had the second highest average biomass (3.04 m^3), and *A. lentiformis* was a close third (3.03 m^3) (Table 12).

Table 12. 85th Street Site 2006 Species Average Biomasses (m^3).

Species	**Shrub plots**	**Windbreak plots**
A. canescens	3.52	3.04
A. lentiformis	4.07	3.03
A. polycarpa	4.05	3.55
L. tridentata	0.14	0.08
P. glandulosa	0.24	0.03
Total	2.74	2.78

The shrub plot treatment with the highest average biomass was deep-pipe/wood chip (4.17 m^3). Second and third, respectively, were surface/wood chip (3.07 m^3) and deep-pipe/mulch (2.40 m^3). At the windbreak plots, average biomass for surface irrigation (3.60 m^3) was higher than for perforated pipe irrigation (1.96 m^3) (Table 13).

Table 13. 85th Street Site 2006 Treatment Average Biomasses (m^3).

Variable		**Biomass**
Shrub plots	Surface/Control	2.20
	Surface/Mulch	2.71
	Surface/Wood chip	3.07
	Deep-pipe/Control	1.86
	Deep-pipe/Mulch	2.40
	Deep-pipe/Wood chip	4.17
Windbreak plots	Surface irrigation	3.60
	Perforated pipe irrigation	1.96

At the 85th Street site shrub plots, the species with the highest performance value was *A. lentiformis* (3.46), followed by *A. polycarpa* (3.20). The treatment with the highest performance value was deep-pipe/wood chips (2.84), followed by surface/mulch (2.03) (Table 14).

Table 14. 85th Street Site 2006 Shrub Plot Performance Values.

Variable		**Performance**
Species	*A. canescens*	2.60
	A. lentiformis	3.46
	A. polycarpa	3.20
	L. tridentata	0.26
	P. Glandulosa	0.08
Treatment	Surface/Control	1.61
	Surface/Mulch	2.03
	Surface/Wood chips	1.78
	Deep-pipe/Control	1.12
	Deep-pipe/Mulch	1.63
	Deep-pipe/Wood chips	2.84

At the 85th Street site windbreak plots, the species with the highest performance value was *A. polycarpa* (3.41), followed by *A. lentiformis* (2.94). Surface irrigation (2.63) had a higher performance value than perforated pipe irrigation (1.43) (Table 15).

Table 15. 85th Street Site 2006 Windbreak Plot Performance Values.

Variable		Performance
Species	*A. canescens*	2.80
	A. lentiformis	2.94
	A. polycarpa	3.41
	L. tridentata	0.03
	P. Glandulosa	0.01
Treatment	Surface irrigation	2.63
	Perforated pipe irrigation	1.43

During the growth period between the 2005 and 2006 monitoring sessions at the 85th Street site, the windbreak plot average plant biomass caught up to the shrub plot average plant biomass. Shrub plot average plant biomass increased by an average of 0.82 m^3, a 42% increase. Windbreak plot average plant biomass increased by an average of 1.57 m^3, a 130% increase (Table 16). The surface-irrigated windbreak plot plants were responsible for this large windbreak plot average plant biomass increase. Windbreak plot plants irrigated by perforated pipe had an average biomass increase of 0.59 m^3, a 43% increase. Surface-irrigated windbreak plot plants had an average increase of 2.58 m^3, a 253% increase (Table 17). This was the first time that the average plant biomass at windbreak plots with surface irrigation was larger than the average plant biomass at plots with perforated pipe irrigation.

Table 16. 85th Street Site 2005-2006 Average Plant Biomass Change at Shrub Plots vs. Windbreak Plots.

	Biomass (m^3)		
Plot Type	**2005**	**2006**	**% Change**
Shrub plot	1.97	2.79	42%
Windbreak plot	1.21	2.78	130%

Table 17. 85th Street Site Windbreak Plot 2005-2006 Average Biomass Change of Surface-Irrigated Plants vs. Perforated Pipe-Irrigated Plants.

	Biomass (m^3)		
Irrigation Method	**2005**	**2006**	**% Change**
Surface	1.02	3.60	253%
Perforated Pipe	1.37	1.96	43%

4.2 Soil Macro- and Micro-nutrient Data

Baseline samples at the Undisturbed site were taken in September 2000, and semiannual sampling began in September 2001. Baseline samples at the 90th Street site were taken in September 1999, and semiannual sampling began in September 2000. The final soil samples at the 90th Street site were taken March 2004. Baseline samples at the 85th Street site were taken in April 2002, and semiannual sampling began in March 2003. Results of data collected on shared sample dates and results of data collected on the March 2006 final sample date of the Undisturbed site and the 85th Street site were examined. Results for the Undisturbed site, the 90th Street site, and the 85th Street site have been displayed in Table 18.

Table 18. Comparison of Macro- and Micro- Nutrient Soil Analyses at the Three Sites.

Site	**Date**	**% OM**	**Nitrates (ppm)**	**Zinc (ppm)**	**Iron (ppm)**	**Copper (ppm)**	**Manganese (ppm)**	**pH**	**Sulfates (ppm)**
Undisturbed	Sep-00	0.50	41.00	0.90	9.00	0.60	12.00	7.50	10.00
	Sep-01	0.70	7.00	1.65	5.50	0.35	8.00	6.90	7.00
	Apr-02	0.50	5.30	0.90	5.30	0.41	7.60	6.90	7.20
	Oct-02	0.55	40.50	0.55	4.00	0.15	7.00	6.75	21.00
	Mar-03	0.20	6.50	0.10	5.50	0.25	1.00	7.50	6.00
	Oct-03	0.10	7.00	0.10	4.50	0.35	2.00	7.60	8.00
	Mar-04	0.15	7.50	0.30	4.00	0.20	1.00	7.75	18.00
	Oct-04	0.70	10.50	0.10	4.50	0.10	4.00	7.10	43.00
	Mar-05	0.55	7.55	0.15	4.00	0.24	3.56	7.50	27.00
	Oct-05	0.50	4.50	0.15	7.50	0.40	2.50	7.30	36.00
	Mar-06	0.65	21.50	0.25	7.50	0.40	4.00	6.95	32.00
90th Street	Sep-99	0.50	19.40	0.30	3.80	0.40	6.30		
	Sep-00	0.40	16.20	0.20	3.80	0.40	5.70	7.90	8.50
	Apr-01	1.20	5.40	0.80	2.60	0.50	7.00	8.10	7.90
	Sep-01	0.93	6.00	0.35	2.40	0.30	6.10	7.90	4.50
	Apr-02	0.86	12.56	0.46	1.20	0.30	5.10	7.90	10.60
	Oct-02	0.71	1.19	0.44	1.00	0.35	5.94	7.79	15.80
	Mar-03	0.57	9.69	0.23	4.63	0.60	2.88	8.21	13.20
	Oct-03	0.45	1.69	0.18	3.44	0.41	3.69	8.04	5.73
	Mar-04	0.28	19.69	0.19	5.19	0.29	2.69	8.46	22.60
85th Street	Apr-02	1.95	45.50	0.75	1.00	1.40	6.50	7.60	926.00
	Mar-03	1.71	55.88	1.51	2.94	1.73	3.69	7.50	371.73
	Oct-03	1.48	108.50	1.19	3.75	1.83	12.56	7.53	538.20
	Mar04	1.26	50.75	1.01	3.06	1.51	4.56	7.86	335.33
	Oct-04	2.17	87.44	0.93	4.00	1.36	10.50	7.53	379.88
	Mar-05	1.94	58.75	0.97	4.10	1.76	6.56	7.50	324.40
	Oct-05	1.73	45.94	1.29	5.31	2.08	6.38	7.71	313.81
	Mar-06	1.83	53.19	1.49	2.69	1.44	2.31	7.79	216.50

The average percent organic matter levels in the soil at the Undisturbed site varied from season to season, but remained stable with a mean value of 0.46% (Figure 7). The average percent organic matter levels at the 90th Street site made a slight decline during the project, with a mean value of 0.66% (Figure 8). The average percent organic matter levels at the 85th Street site remained fairly constant during the project, with a mean value of 1.76% that was larger than the mean values at the Undisturbed site and the 90th Street site (Figure 9).

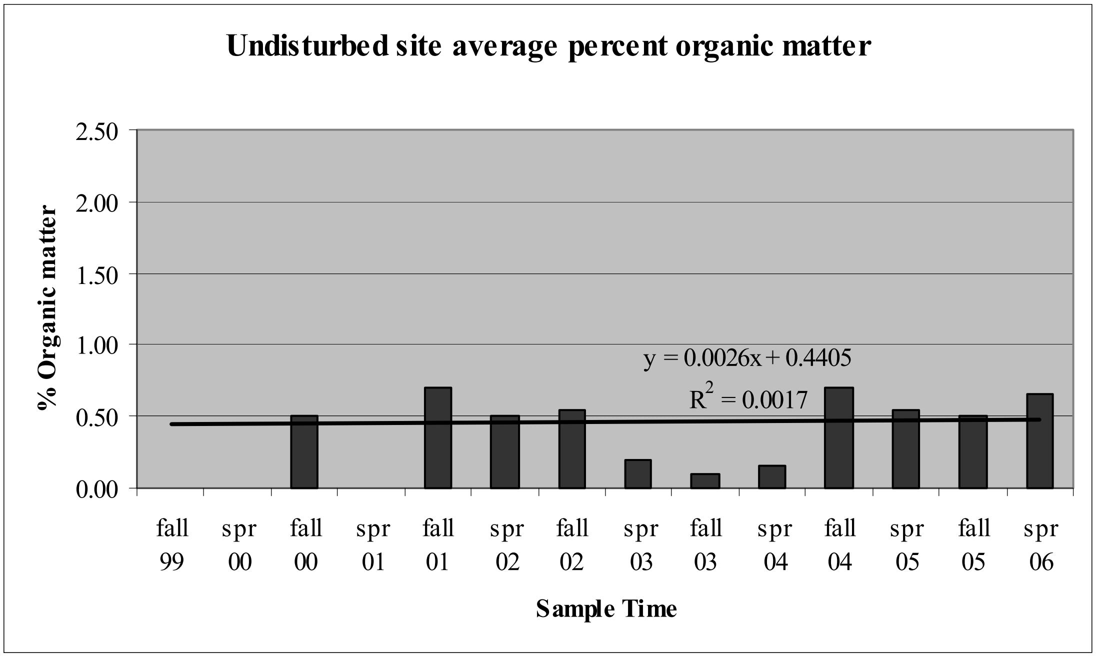


Figure 7. Undisturbed site average percent organic matter of soil samples

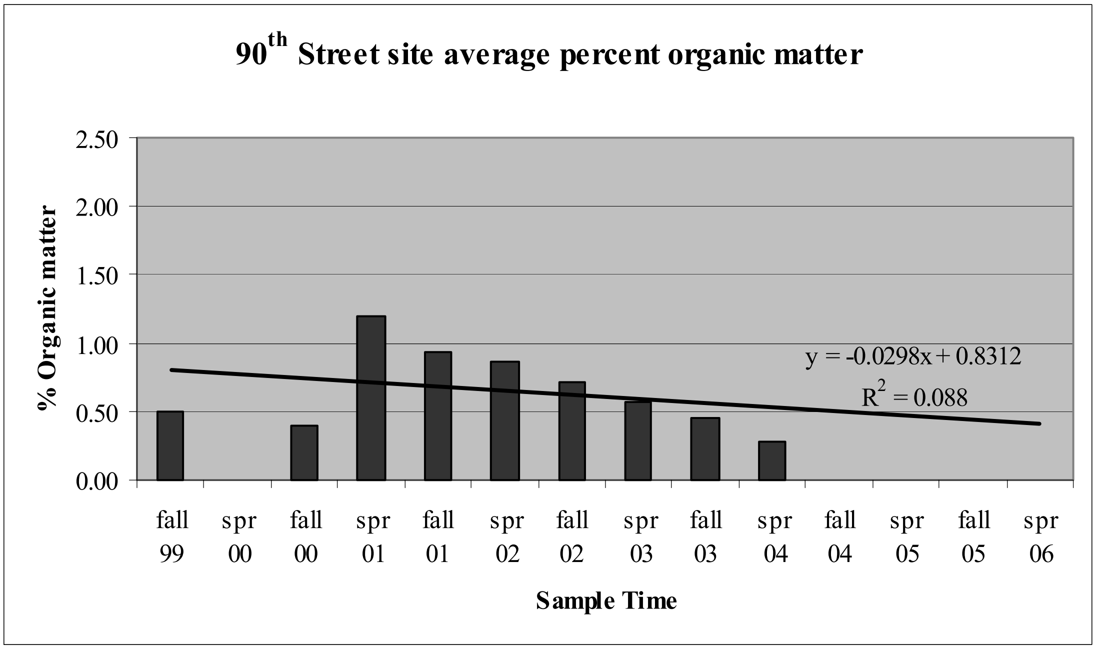


Figure 8. 90th Street site average percent organic matter of soil samples

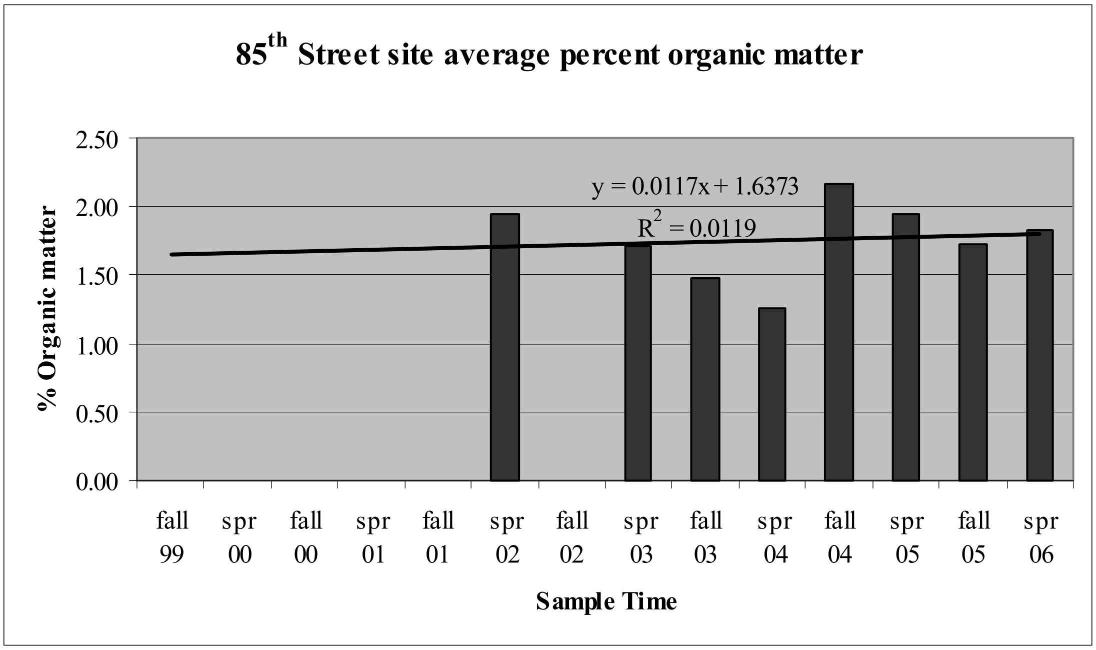


Figure 9. 85th Street site average percent organic matter of soil samples

The average nitrate levels in the soil at the Undisturbed site were extraneously high for samples taken in fall 2000 and fall 2002. These samples were marked with a diagonal line pattern and were not included in nitrate level observations and calculations for the Undisturbed site (Figure 10). The spring 2006 sample may also have been unexpectedly high, but to a lesser degree than the two samples that were excluded from observations and calculations. The average nitrate levels at the Undisturbed site were low and steady, with a mean value of 8.59 parts per million (ppm). The average nitrate levels at the 90th Street site were medium range with a slight decline, with a mean value of 10.20 ppm (Figure 11). The average nitrate levels at the 85th Street site declined and were higher than at the Undisturbed and the 90th Street site, with a mean value of 63.24 ppm (Figure 12).

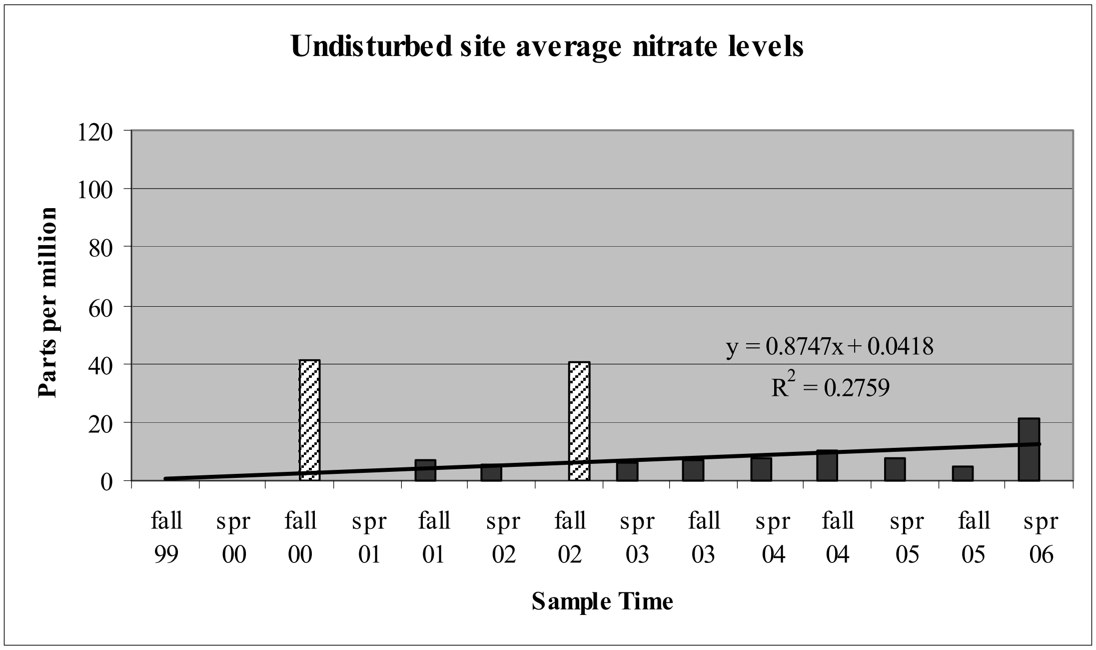


Figure 10. Undisturbed site average nitrate levels of soil samples

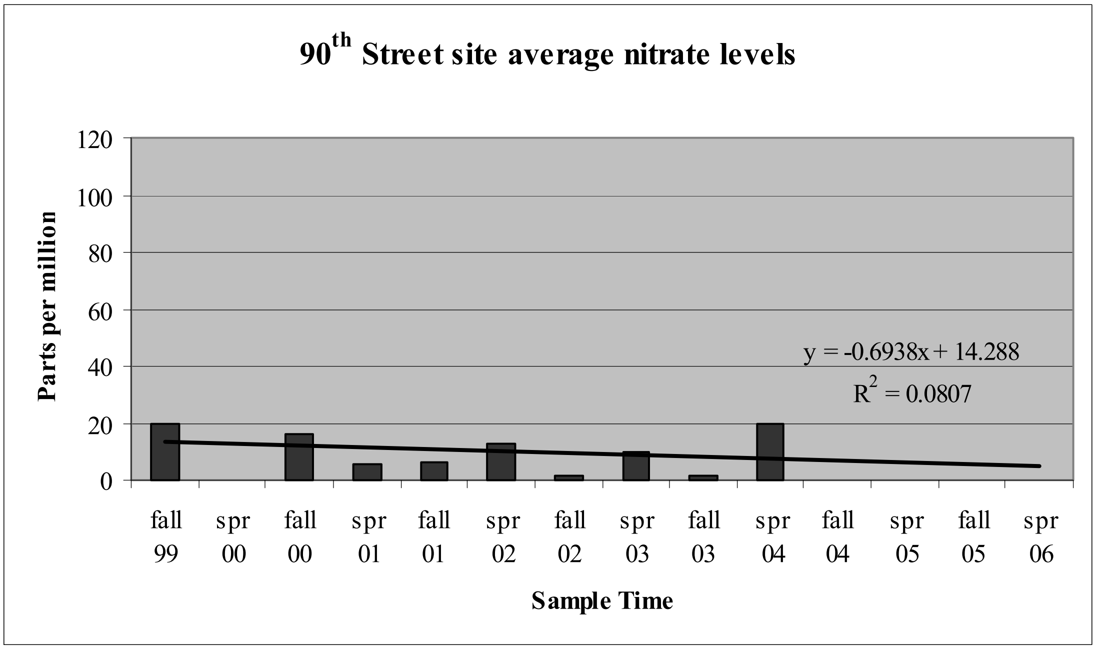


Figure 11. 90th Street site average nitrate levels of soil samples

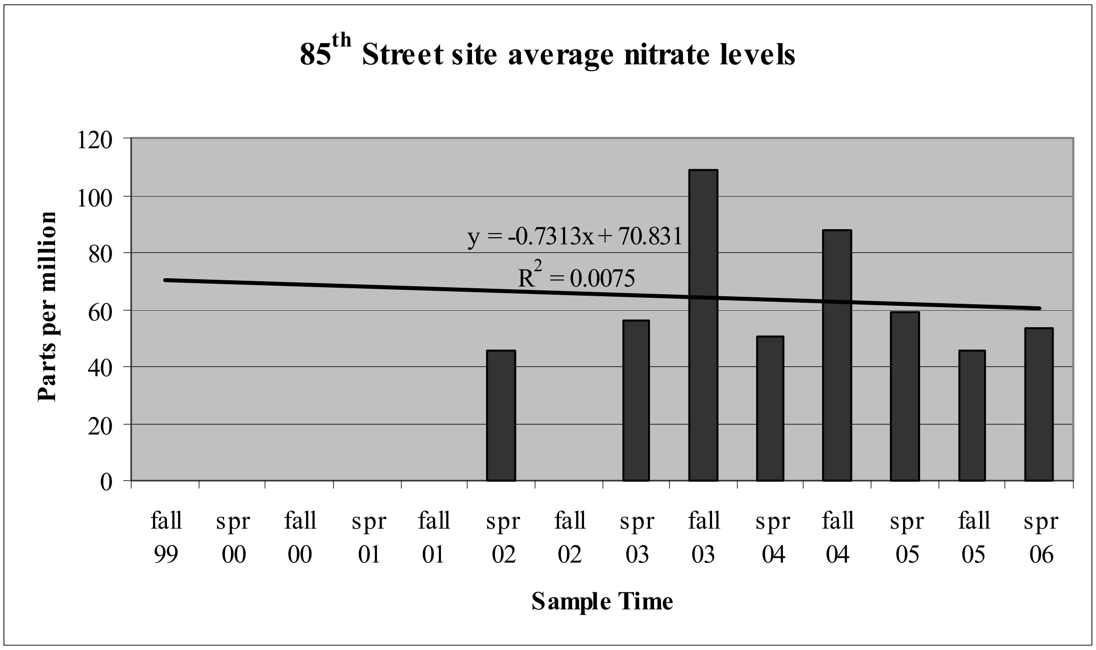


Figure 12. 85th Street site average nitrate levels of soil samples

The average sulfate levels in the soil at the Undisturbed site made an overall increase, but remained low with a mean value of 19.56 ppm (Figure 13). The average sulfate levels at the 90th Street site also made an overall increase, with a similarly low mean value of 11.10 ppm (Figure 14). The average sulfate level at the 85th Street site was extraneously high for a sample taken in spring 2002. This sample was marked with a diagonal line pattern and was not included in sulfate level observations and calculations for the 85th Street site (Figure 15). The average sulfate levels at the 85th Street site declined and were higher than at the Undisturbed and the 90th Street site, with a mean value of 354.26 ppm.

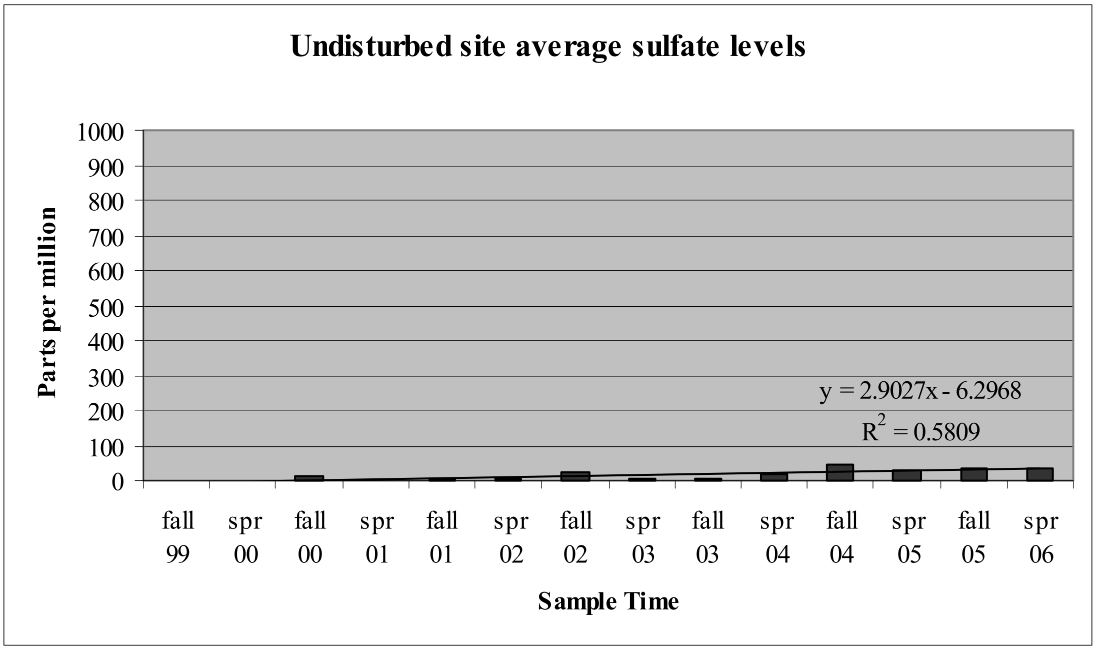


Figure 13. Undisturbed site average sulfate levels of soil samples

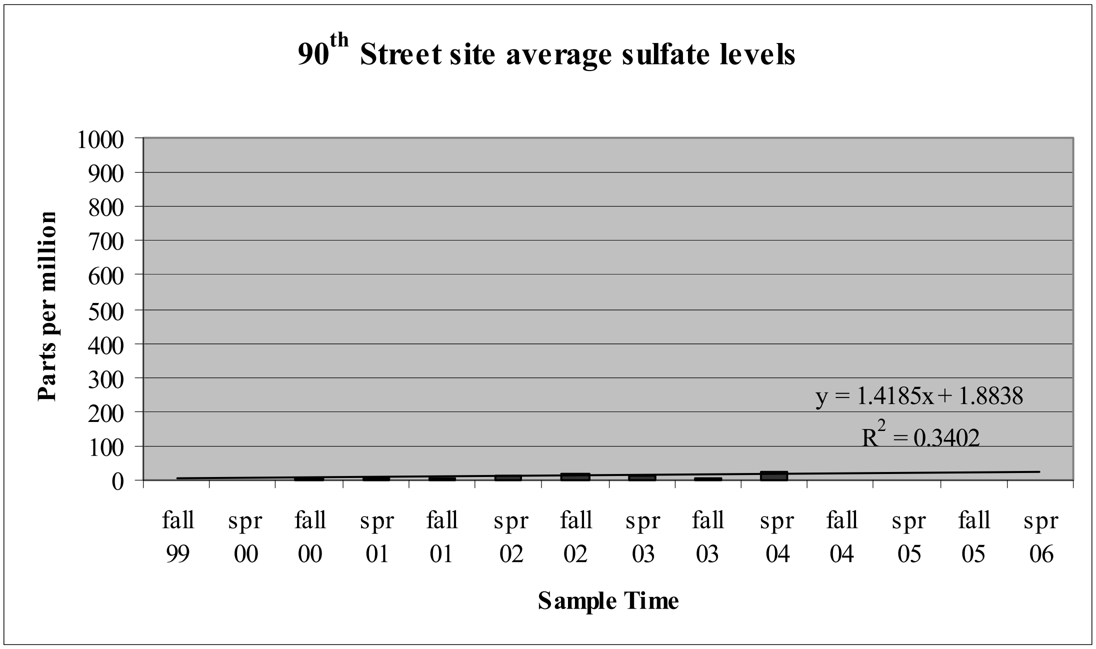


Figure 14. 90th Street site average sulfate levels of soil samples

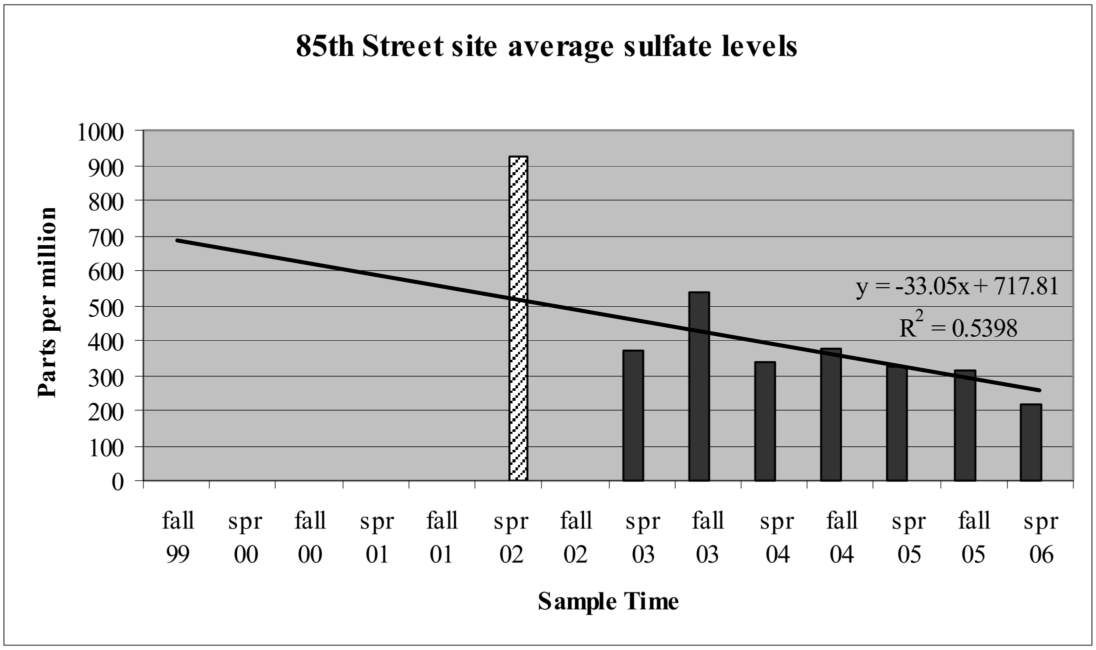


Figure 15. 85th Street site average sulfate levels of soil samples

4.3 Soil Europium Data

As has been the case since spring 2003, fungus measurements were not conducted during the final project year due to a lack of any trend in fungus data appearing over the past several years. Bacteria data have been collected consistently for the length of the project, and were quantified as millions of bacteria per gram of soil. A summary of all soil bacteria levels over the course of the project has been displayed in Table 19.

The average bacteria levels in the soil at the Undisturbed site made a sharp drop from a consistent high to a consistent low after spring 2002, with a mean value of 270 million bacteria per gram of soil (Figure 16). The average bacteria levels at the 90th Street site made a similar but more gradual decline after spring 2002, with a mean value of 351 million bacteria per gram of soil (Figure 17). The average bacteria levels at the 85th Street site made an overall decline. However, there were average bacteria level fluctuations and a final sample that had the third highest average bacteria level among sample averages at the site (Figure 18). The 85th Street site had a mean value of 244 million bacteria per gram of soil, the lowest mean value among the sites.

Table 19. Millions of Bacteria per Gram of Soil.

Site	**Treatment**	**9-99**	**4-00**	**9-00**	**4-01**	**9-01**	**4-02**	**10-02**	**3-03**	**9-03**	**3-04**	**9-04**	**3-05**	**9-05**	**3-06**	**Mean**
	Undisturbed		561	590	584	437	584	119	162	65	31	77	143	50	103	270
90th	Shrub Plot no amendment	201	110	858	420	437	771	273	263	589	78					
90th	Shrub Plot Mulch	278	121	956	823	542	448	457	151	342	142					
90th	Shrub Plot Wood chip	392	21	720	661	562	459	421	136	406	54					
90th	Windbreak	397	82	1002	286	297	589	252	88	189	136					
90th	Average	317	83	884	547	460	567	351	160	38	103					351
85th	Shrub Plot no amendment								364	403	372	71	109	52	271	
85th	Shrub Plot Mulch								537	520	363	68	140	219	329	
85th	Shrub Plot Wood chip								303	452	162	34	108	82	276	
85th	Windbreak								157	550	162	60	146	146	375	
85th	Average								340	481	265	58	126	125	313	244

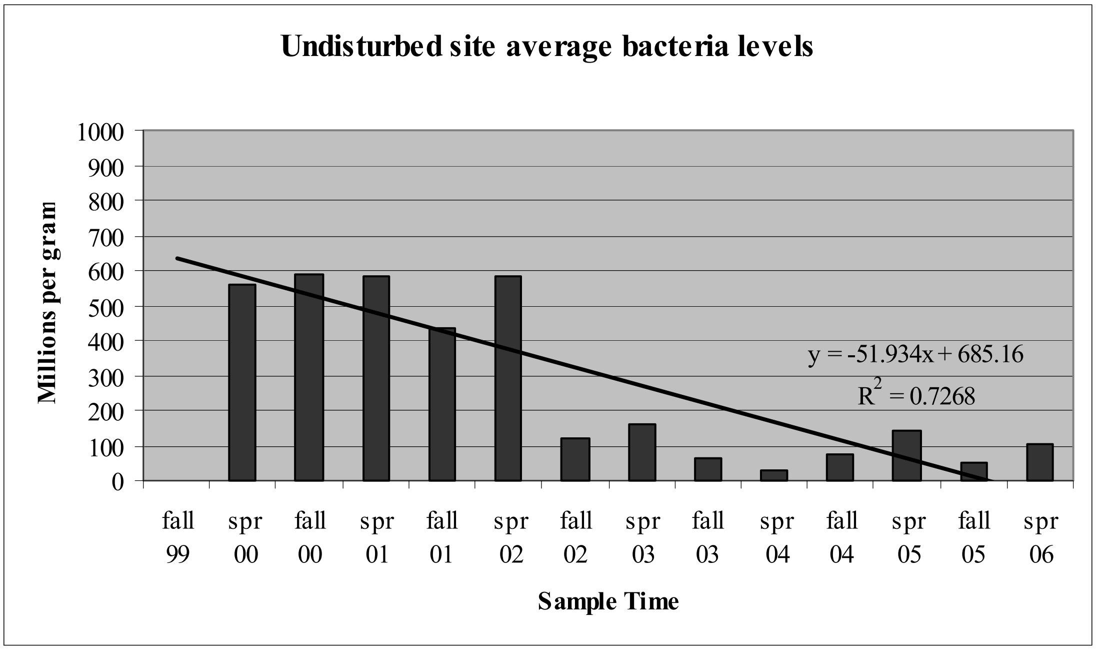


Figure 16. Undisturbed site average bacteria levels of soil samples

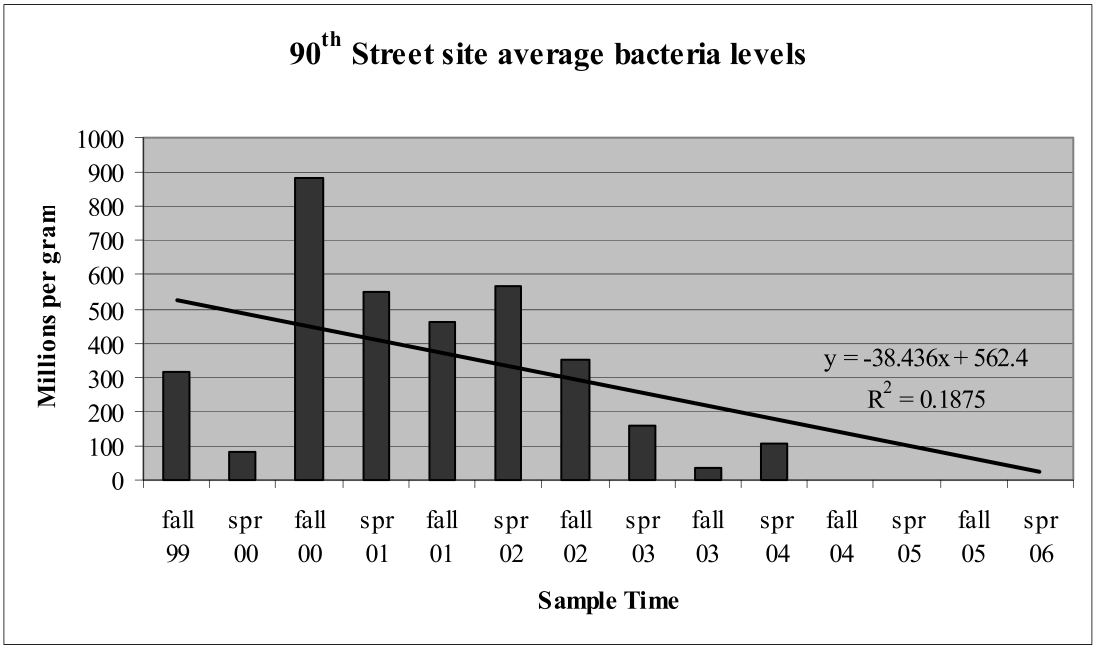


Figure 17. 90th Street site average bacteria levels of soil samples

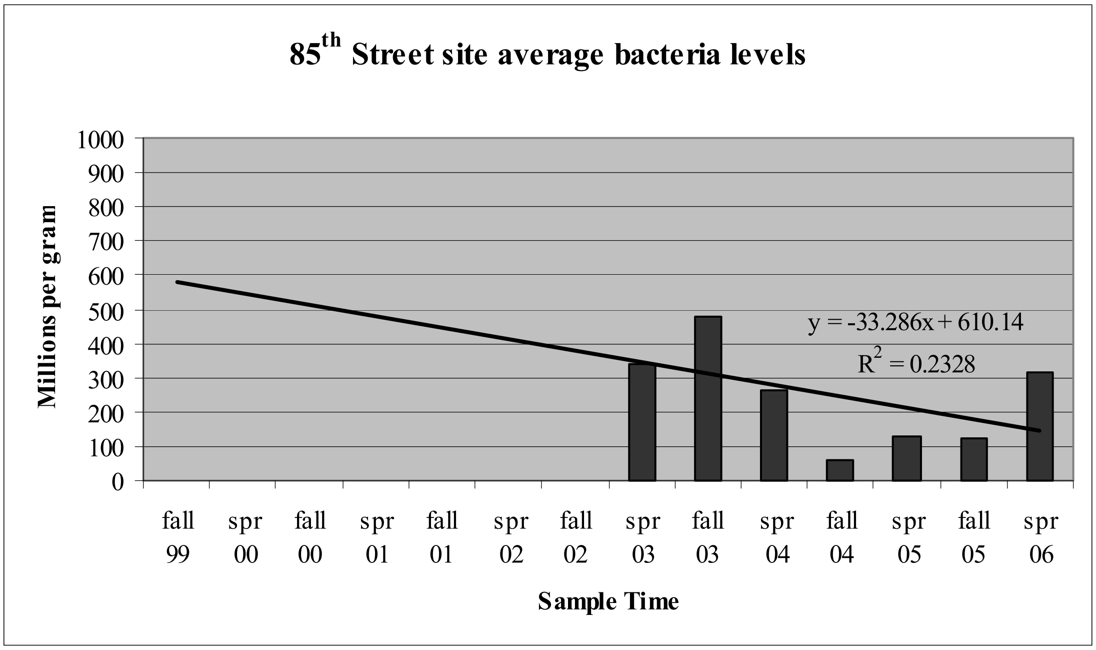


Figure 18. 85th Street site average bacteria levels of soil samples

If one treatment was to consistently have the least bacteria per gram in soil samples that were collected, that treatment would possibly be the most desirable for restoration of the mineralization cycle. Neither the 90th Street site nor the 85th Street site had a treatment that consistently had the least bacteria per gram in soil samples that were collected (Figures 19 and 20). Never did the bacteria level rankings of treatments at the 90th Street site and the 85th Street site match during the shared sample dates from spring 2003 to spring 2004. Soil sample dates that showed common changes in bacteria levels among different sites were uncommon. The only example of a common change was between spring 2002 and fall 2002 (Table 19), when millions of bacteria per gram of soil decreased from 584 to 119 at the Undisturbed site and from 567 to 351 at the 90th Street site.

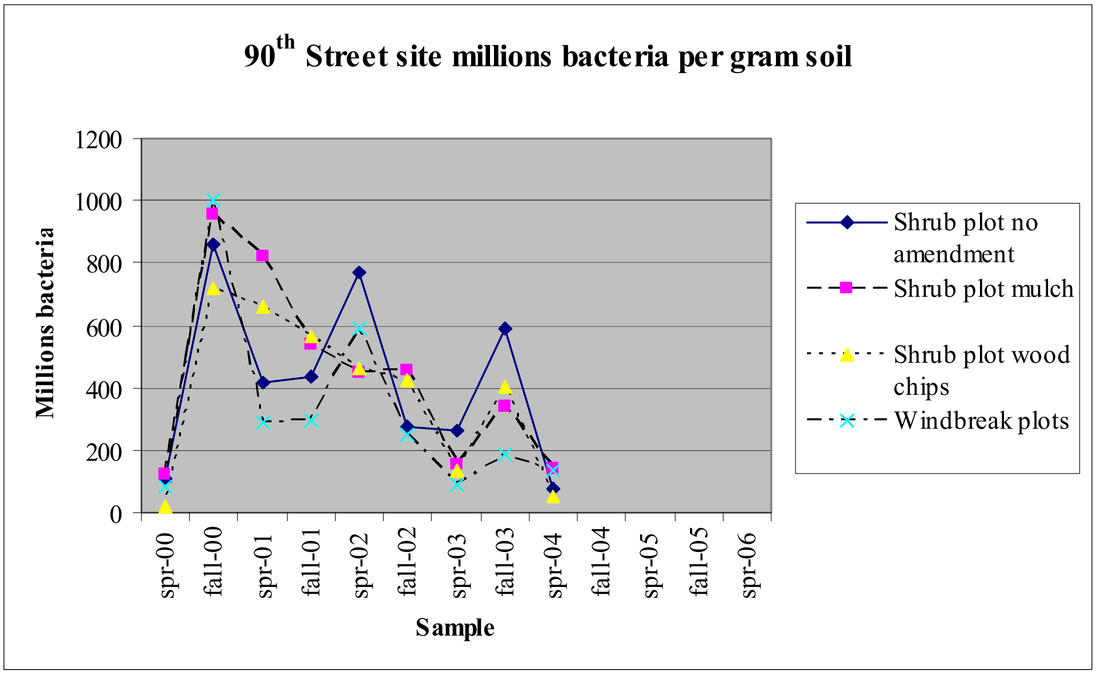


Figure 19. 90th Street site average bacteria levels of soil samples from each treatment

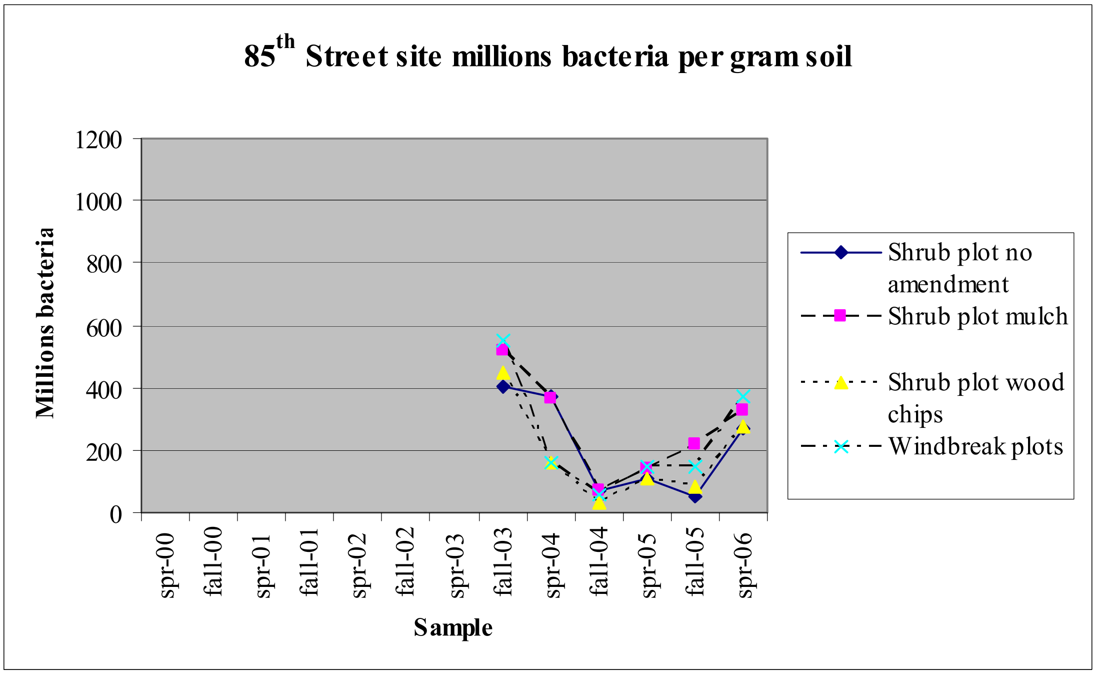


Figure 20. 85th Street site average bacteria levels of soil samples from each treatment

5.0 DISCUSSION

5.1 Survival, Biomass and Performance Values

It was apparent early on that the *Atriplex* species were better performers than *L. tridentata* and *P. glandulosa* on the fallow farmlands that were used for this project. They repeatedly dominated in survival and biomass at both the 90th Street site and the 85th Street site. Only the 90th Street site 2004 windbreak plot species performances ranked *P. glandulosa* third and *A. lentiformis* fourth, with respective performance values of 0.84 and 0.80. The *Atriplex* species continued to outperform *L. tridentata* and *P. glandulosa* through the final monitoring session at the 85th Street site in March 2006.

A previous SERG project, titled Revegetation and Erosion Control of Pioneer Site and Pioneer Trail at National Training Center Fort Irwin, CA, resulted in survival statistics that were markedly different from survival statistics at this project. The previous project lasted one-year and involved (among other species) *A. canescens*, *A. polycarpa*, *L. tridentata* and *P. glandulosa*. At Pioneer Site, the top two survivors were *P. glandulosa* (100%) and *L. tridentata* (86.6%). *Atriplex* species averaged 55.2% survival. At Pioneer Trail, the top two survivors were *L. tridentata* (70%) and *P. glandulosa* (66.6%). *Atriplex* species averaged 36.4% survival. *Atriplex* species survived at lower percentages than *L. tridentata* and *P. glandulosa* at each site.

The project sites of Revegetation and Erosion Control of Pioneer Site and Pioneer Trail at National Training Center Fort Irwin, CA have critical differences from the 90th Street site and the 85th Street site. The two projects were conducted for different lengths of time. During the year that the Revegetation and Erosion Control of Pioneer Site and Pioneer Trail at National Training Center Fort Irwin, CA project was conducted, no irregular weather conditions were reported. This lowers the probability that differences in time and weather were factors in the survival percentage results and differences. Pioneer Site and Pioneer Trail both represent disturbed desert land that has never been farmed. The soils of Pioneer Site and Pioneer Trail were highly compacted, and they were not ripped prior to planting. The soils of the 90th Street site and the 85th Street site were compacted, but they were prepared by ripping at 30 cm depth. In the process, dead, non-native, plant material was incorporated into the soils to provide additional organic matter. The soil composition, chemical and ecological properties, and site preparation of the Antelope Valley sites presented plants with a disturbed but less stressful environment that is characteristic of fallow farmlands. The superior survival of the *Atriplex* species at the 90th Street site and the 85th Street site is most likely due to an ability to out-compete *L. tridentata* and *P. glandulosa* under the conditions that were created. Chemical properties indicative of fallow farmland soil include high macro- and micro-nutrient levels and a level of soluble salts that is higher than in unaltered desert soil. Increased soil salinity gives *Atriplex* species an advantage because of their high tolerance for soluble salts in soils.

The deep-pipe/wood chip treatment combination had the best shrub plot treatment performances at both the 90th Street site and the 85th Street site. The superior performance of deep-pipe irrigation in shrub plots was anticipated because of results from a previous SERG arid landscape project involving deep-pipe and surface irrigation treatments. The previous SERG project, titled Irrigation and Mulch Effects on Desert Shrub Transplant

Establishment, took place near the lower San Felipe Creek in the Sonoran Desert east of San Diego, CA. *P. glandulosa* was treated with deep-pipe irrigation and with surface irrigation. The project concluded that shrub plots treated with deep-pipe irrigation had an advantage over shrub plots treated with surface irrigation. Deep-pipe irrigation better adapted plants to survive on their own by "…enabling them to escape severe herbivory, suggesting that more robust plants with extensive root systems had developed (Bainbridge, D.A., et al. 2001)" as a result of deep-pipe irrigation. A previous SERG project titled Irrigation and Mulch Effects on Desert Shrub Transplant Establishment researched treatment with mulch as a soil amendment to conserve moisture in very arid environments. Mulch had been effective in other projects, but was not effective for the Irrigation and Mulch Effects on Desert Shrub Transplant Establishment project. Mulch is a potential risk because it only provides "…benefits when sufficient rain falls to cause surface ponding and sheet flow (Bainbridge, D.A., et al. 2001)." Such ideal conditions were unlikely at the 90th Street site and the 85th Street site. Bainbridge, D.A., et al. 2001 refers to a study by Jalota and Prihar (1998) that found mulch to be of little value or detrimental in low rainfall periods. Mulch can intercept moisture from light rains before it reaches the soil. Mulch can also wick moisture from the soil into the air, increasing evaporation.

The inconsistency of *Atriplex* species and treatment combination performance rankings between the 90th Street site and the 85th Street site due to differences in physical, chemical and ecological properties of the soils at the sites can be used advantageously when revegetating or restoring fallow farmland. Results of a revegetation or restoration effort may be maximized by selecting the species and treatment combination best suited to the conditions of a site.

5.1.1 90th Street Site

The best performance value among plot, treatment and species combinations at the 90th Street site occurred for windbreak plots irrigated with perforated pipe and planted with *A. canescens*. In this scenario, *A. canescens* had a performance value of 3.38 and perforated pipe irrigation had a performance value of 1.52. If a fallow site is to be restored permanently with more than one species, *A. polycarpa* had a performance value of 1.64 and would be recommended for such a project.

Shrub plots have the advantages of requiring less time and money to construct, and being easier to adapt to irregularly shaped pieces of land. Should a shrub plot be the more applicable layout for a revegetation or restoration project, the treatment and species combination that would be recommended is deep-pipe/wood chips (1.03) planted with *A. polycarpa* (2.17). The disadvantage to such a planting arrangement and treatment combination is that plants irrigated with deep-pipe must be watered individually by hand. If a fallow site is to be restored permanently with more than one species, *A. canescens* had a performance value of 1.85 and would be recommended for such a project.

5.1.2 85th Street Site

The best performance value among plot, treatment and species combinations at the 85th Street site occurred for shrub plots with the deep-pipe/wood chip treatment combination and planted with *A. lentiformis*. In this scenario, *A. lentiformis* had a performance value of 3.46 and the deep-pipe/wood chip treatment combination had a performance value of 2.84. If a fallow site is to be restored permanently with more than one species, *A. polycarpa* had a performance value of 3.20 and would be recommended for such a project.

Performance values as analyzed in this project rank windbreak plots irrigated with surface irrigation (2.63) and planted with *A. polycarpa* (3.41) after shrub plots with the deep-pipe/wood chip treatment combination and planted with *A. lentiformis*. These performance values are only growth statistics; they fail to display the capacity for shrub plots and windbreak plots to mitigate airborne dust. They also do not give long term results. This project is limited to recommendations based on calculated performance values based on less than five years of data. However, when the total biomasses of all plants in each individual windbreak were calculated at the 85th Street site in 2006, trends suggested that the more protected windbreaks located towards the center of the plots had higher total biomasses than the windbreaks on the edges that were most exposed to the wind. Increased protection from wind may raise the biomass and therefore dust mitigation potential of plants. Therefore, although windbreak plots irrigated with surface irrigation and planted with *A. polycarpa* rank after shrub plots treated with the deep-pipe/wood chip combination and planted with *A. lentiformis*, if land is to be permanently restored there may be an advantage to the windbreak plot planting arrangement. If a fallow site is to be permanently restored with the windbreak plot planting arrangement irrigated with surface irrigation and planted with more than one species, *A. lentiformis* had a performance value of 2.94 and would be recommended for such a project.

Plants with windbreak plot surface irrigation and perforated pipe irrigation treatments did not survive at significantly different percentages at the 90th Street site or the 85th Street site. Windbreak plot mean biomasses at the 90th Street site in 2004 were higher for perforated pipe irrigation than for surface irrigation. The same was true at the 85th Street site until surface irrigation made a 253% increase in biomass between June 2005 and June 2006 to overtake perforated pipe irrigation for a higher mean biomass. No other treatment underwent this dramatic biomass increase. After supplemental irrigation to a site has ended, precipitation is a key variable when comparing treatments that differ in irrigation method. A history of the monthly rainfall recorded from the Lancaster Flight Service Station in Lancaster, CA (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca4749), provides climatic information for the project (Table 20). The period between June 2005 and June 2006 was the only year when fall seasonal precipitation began in September. Inches of monthly rainfall remained fairly consistent until June 2006. Surface irrigated plants had basins that may have given them an advantage over plants irrigated with perforated pipe by collecting rainwater. It is possible that these conditions resulted in the 253% biomass increase at surface-irrigated windbreak plots.

Table 20. Lancaster, CA, Monthly Total Precipitation (Inches) from 1999-2006.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	1.35	0.49	0.00	0.89	0.00	0.18	0.95	0.00	0.00	0.00	0.04	0.00	3.90
2000	0.00	1.76	1.12	1.82	0.00	0.08	0.00	0.00	0.00	0.32	0.01	0.00	5.11
2001	1.17	3.73	0.66	0.58	0.00	0.00	0.02	0.00	0.00	0.24	0.60	0.63	7.63
2002	0.20	0.06	0.30	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.66	1.19	2.45
2003	0.00	3.55	0.71	0.96	0.27	0.00	0.11	0.00	0.00	0.23	0.32	0.57	6.72
2004	0.01	1.88	0.23	0.05	0.00	0.00	0.00	0.00	0.00	1.93	0.15	3.65	7.90
2005	5.26	4.71	0.72	0.57	0.50	0.00	0.16	0.01	0.80	1.77	0.00	0.19	14.69
2006	0.83	1.00	1.02	0.68	0.02	0.00	0.02	0.00	0.00	0.09	0.00	0.34	4.00
Average (1974-2006)	1.55	1.89	1.32	0.37	0.13	0.05	0.10	0.14	0.20	0.38	0.44	1.09	8.00

5.2 Soil Macro- and Micro-nutrients and Europium Data

Change in macro- and micro- nutrient and microorganism levels in desert soils, such as Antelope Valley, like all natural processes in arid and semi-arid ecosystems, is an extremely slow process and very dependent on climatic factors, such as temperature and precipitation. Water is required for the mineralization process to occur and even a few wet years will do little to change the overall picture of soil microorganism levels. There are no time tables as to how long it takes to convert a disturbed soil back to a more natural soil since soil is so variable and the processes involved, i.e., mineralization, nitrification, denitrification, and nitrogen immobilization are very dependent on such variable factors as climate, vegetation, animal communities, and human impacts. Natural and/or anthropogenic restoration processes can take an extremely long time to display effects and may be measured in decades, with extremely fast changes sometimes occurring within 5-10 years and extremely slow changes taking over 100 years to display actual results (Zink, 2006).

The macro- and micro-nutrient levels and the microorganism level at the Undisturbed site are to be referenced as values typical of a natural or restored desert habitat. A goal of this project was to track the 90th Street site and the 85th Street site macro- and micro-nutrient and microorganism levels with the expectation that values at these sites are approaching the values at the Undisturbed site. The key variable between the 90th Street site and the 85th street site was the time since each was last farmed. Differences in the levels and rates of change of values at these sites are mostly attributed to this key variable.

Although some high and low values at sites may not be explainable, the fact that some patterns exist is a positive sign. It is important to realize that desert soil restoration relies on slow processes. The seven years of research invested in this project is only a fraction of the time that fallow farmland would be expected to take before being fully restored. Values from the Undisturbed site are a benchmark for natural macro-and micro- nutrient levels, but an attempt to calculate approximate soil restoration times by inserting the benchmark values as independent variables in the equations from figures 8-18 would give inaccurate approximations. This project was not intended to predict the time necessary for restoration of fallow agricultural soil.

It is important to note that each variable in figures 8-18 was graphed on a common scale for all three sites. The 85th Street site commonly had much higher values, and seasonal differences that created trends at this site may have been larger than the seasonal differences at the Undisturbed or the 90th Street site. Therefore, before a sloping trendline is stated to be demonstrating a pattern of change at a site, the amount of change in relation to the scale must also be taken into account.

At the Undisturbed site, the percent organic matter fluctuated but remained fairly constant. The fall 1999 and fall 2000 soil samples at the 90th Street site were on the lower end of the scale before percent organic matter made a rise followed by a consistent decline starting in spring 2001. Fall 1999 and fall 2000 soil samples may have been taken from spots that were lower in percent organic matter. If at the beginning of the project the percent organic matter at the 90th Street site was still at an elevated level from farming, the level went down to finish within the range of the Undisturbed site. The percent organic matter in the soil at the 85th Street site was higher than at the 90th Street site, and did not appear to be making a decline by the final soil sampling date in spring 2006. This high percent organic matter may have been connected to high nitrogen levels.

The spikes in the fall 2000 and fall 2002 nitrate levels at the Undisturbed site are likely due to unexpectedly high levels at the spots from which the samples were collected. The final soil sample in spring 2006 appears to be the only reason why the trend line shows a rising nitrate level at the Undisturbed site. The nitrate level at the Undisturbed site is therefore determined to be stable and unchanging. The average nitrate level at the 90th Street site was ultimately lower than at the Undisturbed site. Low nitrate levels in fall 2002 and fall 2003 may have been due to low levels at the spots from which the samples were collected. The 90th Street site average nitrate level of 10.20 which is lower than the Undisturbed site average of 14.44 may be due to these individual samples. It may also be linked to low percent organic matter. The pattern of decreasing nitrate levels displayed by the trend line in figure 5 is unlikely to continue. Levels are within the range of the Undisturbed site. When farming stopped at the 90th Street site, nitrate levels were probably similar to the levels recorded at the 85th Street site. At the 85th Street site, nitrates are still at an elevated level due to recent farming. The decline of the soil nitrate level demonstrated by the trend line in figure 6 is expected to continue.

The natural sulfate level of desert soil is expected to be low and steady. Sulfate levels recorded at the Undisturbed site meet these expectations. Sulfate levels at the 90th Street site averaged lower than at the Undisturbed site. These values showed no decline, and had most likely already arrived at the restored soil level in fall 1999 when the project began. The decline of sulfate levels at fallow sites is probably more rapid than the decline of nitrate levels. The 85th Street site had an extraneously high sulfate level from a sample collected in spring 2002. With that sample eliminated from the trend, the level of sulfates at the 85th Street site appears to be declining rapidly towards the baseline level.

Shrub dominated habitats, such as those naturally found in the Mojave Desert, typically have a mineralization cycle dominated by fungi. Disturbed habitats, dominated by non-native annual species, typically have a mineralization cycle dominated by bacteria. The mineralization cycle at the 90th Street site appears to be mimicking that of the Undisturbed site. The bacteria level that is higher at the 90th Street site may be due to the organic matter ripped into the soil during site preparation. This indicates that in about twenty years, a post agricultural mineralization cycle can be restored to natural levels. For all of the macro- and micro-nutrients discussed, the 85th Street site had the highest levels. The results for bacteria levels show a different pattern. Bacteria levels in the soil at the 85th Street site were lower than at the Undisturbed site and the 90th Street site. Pesticides may have killed microorganisms at the 85th Street site. It is likely that pesticides that had accumulated at the 90th Street site before it was abandoned resulted in low microorganism levels at the fallow site. The 90th site appears to have lain fallow long enough for pesticides to disperse and microorganism levels to increase. The bacteria levels at the 85th Street site began to increase from fall 2004 until the final sampling date in spring 2006. Through active restoration, a site such as the 85th Street site may be restored in a minimum of twenty years.

Bacteria play a major role in the mineralization of non-recalcitrant matter, as opposed to fungi, which serve as the primary decomposers for the more complex, recalcitrant, organic matter. Non-recalcitrant matter is made up of simple carbon compounds found in both non-native and native annuals. Recalcitrant matter is made up of more complex carbon compounds such as those found in bark, wood chips, and perennial, woody shrubs. With very few exceptions, recalcitrant organic matter must first be broken down from complex to simple carbon compounds by fungi. Once this occurs, bacteria finish the decomposition process. Because of this, changes in bacterial numbers develop much faster than changes in fungal activity. Changes in fungal activity, due to their role in the slower decomposition of more complex organic matter, are much slower to appear. It is not surprising that treatment combinations showed no consistent ranking pattern at the 90th Street site or the 85th Street site. Differences in irrigation or soil amendments are unlikely to play a significant role in the mineralization cycle during such a short project. Any significance that these treatments may play would likely only be apparent over a longer period of time. Any immediate changes may have been the result of decomposition of the non-recalcitrant non-native plants that were mixed into the soils during site preparation.

The relationship between microorganisms and soil nutrients normally displays itself as a trend when looking at the levels of organic matter, nitrogen, and bacteria, over time. As bacteria break down non-recalcitrant material such as herbs, the percent of organic matter in the soil drops and levels of nitrogen increase in the form of nitrates. The high level of nitrates in the soil facilitates more growth of non-native annuals, which are nitrophilic organisms. When a desert community is dominated by perennial shrubs, bacteria cannot begin the decomposition process first because the organic matter is too complex; fungi need to break down this recalcitrant, woody, material to more simple compounds. With this condition in the soil environment, nitrates are made available at a much slower rate, curbing the rampant growth of non-native annuals. When performing restoration of fallow desert farmland over an extended period of time, a decrease in bacteria and an increase in fungal numbers can be expected.

6.0 REFERENCES

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