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Basalt Waste Isolation Project Reclamation Support Project 1991-1992 Report

C. A. Brandt
W. H. Rickard, Jr.
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June 1992

Prepared for the U.S. Department of Energy
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SUMMARY

The Basalt Waste Isolation Project (BWIP) Reclamation Support Project began in the spring of 1988 by categorizing sites disturbed during operations of the BWIP into those requiring revegetation and those to be abandoned or transferred to other programs. The Pacific Northwest Laboratory's role in this project was to develop plans for reestablishing native vegetation on the first category of sites, to monitor the implementation of these plans, to evaluate the effectiveness of these efforts, and to identify remediation methods where necessary. The Reclamation Support Project focused on three major areas: geologic and hydrologic boreholes, the Exploratory Shaft Facility (ESF), and the Near-Surface Test Facility (NSTF).

A number of BWIP reclamation sites seeded between 1989 and 1990 were found to be far below reclamation objectives. These sites were remediated in 1991 using various seedbed treatments designed to rectify problems with water-holding capacity, herbicide activity, surficial crust formation, and nutrient imbalances. Remediation was conducted during November and early December 1991. Sites were examined on a monthly basis thereafter to evaluate plant growth responses to these treatments. At all remediation sites, early plant growth far exceeded any previously obtained using other methods and seedbed treatments. Seeded plants did best where amendments consisted of soil-plus-compost or fertilizer-only. Vegetation growth on Gable Mountain was less than that found on other areas nearby, but this difference is attributed primarily to the site's altitude and north-facing orientation.

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INTRODUCTION

The Basalt Waste Isolation Project (BWIP) Reclamation Support Project began in the spring of 1988 by categorizing sites disturbed during operations of the BWIP into those requiring revegetation and those to be abandoned or transferred to other programs. The Pacific Northwest Laboratory's role in this project was to develop plans for reestablishing native vegetation on the first category of sites, to monitor the implementation of these plans, to evaluate the effectiveness of these efforts, and to identify remediation methods where necessary. The Reclamation Support Project focused on three major areas: geologic and hydrologic boreholes, the Exploratory Shaft Facility (ESF), and the Near-Surface Test Facility (NSTF).

In the fall of 1988, 21.8 ha of boreholes were seeded with native grasses, consisting primarily of Sandberg's bluegrass (*Poa sandbergii*), bottlebrush squirreltail (*Sitanion hystrix*), and needle-and-thread grass (*Stipa comata*). Seeding was completed on October 31, 1988. Average density of Sandberg's bluegrass on these sites after the first growing season was approximately 45 plants/m^2. Sandberg's bluegrass failed to establish on 2.8 ha and was below the necessary objectives for percentage cover on an additional 0.5 ha. Big sagebrush tubelings were planted on three sites during March 1989. Shrub mortality averaged 50%. These findings, and a brief history of the BWIP itself, were documented in an interim reclamation report (Brandt et al. 1990a).

Revegetation of the remaining boreholes began with seedbed preparation and seeding October 1989. Subsequent planting of shrubs was completed December 8, 1989. Approximately 58% of all borehole reclamation sites were found to be well below their respective reclamation objectives, with 25% of sites devoid of grass or shrub growth. Analyses indicated that the primary causes of failure were the lack of winter rains during 1989-1990, exposure to drying winds, grazing by blacktailed jackrabbits (*Lepus californicus*) on shrubs, and residual herbicide activity on some sites (Brandt et al. 1991a).

The ESF was seeded with grasses and shrubs during November 1988. Spiny hopsage (*Grayia spinosa*) tubelings were planted during March 1989. The site was irrigated at the rate of 2.5 cm (1 in.) total precipitation each month from March to

July 1989 (Brandt et al. 1990b). Although there was a great deal of spatial variability in cover of seeded grasses, the average density over the entire ESF was above the revegetation objective. Average density of Sandberg's bluegrass in December 1989 was 16 plants/m^2. The mound over the former ESF drill rig collar was nearly devoid of vegetation. All shrubs except spiny hopsage were below reclamation objectives. Mortality of spiny hopsage averaged over 50%. These findings were documented in a final reclamation report for the ESF (Brandt and Rickard 1990).

The NSTF was divided into six distinct areas: the water line, borrow pit, trailer village, bench area, box cuts, and generator/ventilation pad areas. Earthwork at the NSTF, consisting of the removal of mined materials and restoration of original grades, was completed November 3, 1988. Coarse gravels and soils salvaged from borehole reclamation were used to bring the borrow pit and box cuts to grade, and were applied to the generator/ventilation pad areas to provide a topsoil for supporting vegetative growth. The site was subjected to herbicide fallow through August 1989. Seeding at the NSTF was completed on November 3, 1989, and subsequent planting of shrubs was completed on November 20, 1989. The water line, trailer village, and borrow pit areas were irrigated up to a maximum of 2.5 cm/mo (1 in./mo) from March to June 1990. Growth of all species on the bench area and trailer village during the first growing season was excellent. Sites brought up to grade using scavenged fill materials supported no plants whatsoever. This failure was thought to be a result of a combination of residual herbicide activity in and poor moisture-holding capacity of the scavenged borehole material (Brandt et al. 1991c).

Because of the failures to establish appropriate vegetation on many sites, the objectives of the final phase of the BWIP Reclamation Support Project were to determine the causes of vegetation growth failure, develop plans for remediating substandard sites, and evaluate the effectiveness of that remediation. The remainder of this report documents the results of these efforts.

TASK REPORTS

Work for the final phase of the project was divided into four tasks: 1) identifying sites requiring remediation, 2) identifying the causes of past vegetation failure, 3) developing methods for remediating sites, and 4) evaluating the success of the remediation.

TASK 1: IDENTIFICATION OF REMEDIATION SITES

Sites to be remediated were identified using a two-stage process. In the first stage, data on vegetation growth at all sites were compiled and compared to plant cover and density averages obtained from the 100-m^2 control plots that were established in 1988 in undisturbed habitat. Average plant density on the revegetated sites was then compared to the average density of plants in the undisturbed habitats. Sites below reclamation objectives were identified as those sites that were at least 20% below the grass density in the appropriate control habitat. These are identified in Table 1.

TABLE 1. Sites >20% Below Reclamation Objectives. Shaded sites were remediated.

DB-12	DH-19	RRL-7
DB-14	DH-27	RRL-9
DB-15	DH-28	RRL-10
DC-7/8	DH-35	RRL-16
DC-12	McGee	NSTF Water Line-West
DC-16	Obrian	NSTF Borrow Pit
DC-18	RRL-4	NSTF Box Cuts
DC-20	RRL-5	NSTF Generator/Ventilation

Sites identified as being below the reclamation objective in terms of vegetative cover were then further reduced in number by excluding from consideration those sites within industrial portions of the Hanford Site (e.g. the

200-West Area) and areas too small or too near ongoing disturbance to serve as wildlife habitat. Those sites that could serve as wildlife habitat were selected for remediation and are identified by shading in Table 1.

TASK 2: CAUSAL ANALYSIS OF REVEGETATION FAILURE

The objective of this task was to identify the primary causes of plant failure on the sites identified for remediation. Soil samples were collected from at least four locations at each remediation sites during the spring of 1991. Physical and nutrient analyses of these samples were conducted by the Oregon State University Soils Laboratory. In general, soils of all remediation sites were extremely low in nutrients, especially nitrogen and phosphorus (Table 2). Sites where salvaged borehole materials had been applied were not significantly lower in total nitrogen and phosphorus than were soils on the remaining remediation sites; however, they did have a much higher proportion of organic carbon from the heavy mulches that were applied to these sites after seeding. These mulches were not degraded during the intervening winter because of the lack of soil microorganisms. The resulting high carbon:nitrogen ratio would lower the availability of nitrogen to growing plants (Brandt and Hendrickson 1991).

The elements required for plant growth, except carbon and oxygen, are obtained by terrestrial plants from the soil. Nutrients required in relatively large amounts include nitrogen, phosphorus, and potassium. Micronutrients are required in only trace amounts (Table 3). All nutrients except nitrogen become available through weathering of minerals in the parent soil.

After water, the primary factor limiting plant growth in semiarid lands is nitrogen, in part because it is not a component of soil base material (Skujins 1981; Whitford 1988). Nitrogen exists mainly in gaseous form in the air and is made available to plants through the action of nitrogen-fixing microorganisms, such as bacteria and blue-green algae, that occur as free-living organisms in well-developed soils, or as symbionts with certain plants such as legumes. Nitrogen may also be added to the soil dissolved in rainwater. Primary sources of nitrogen for soils on the Hanford Site are precipitation and nonsymbiotic fixation by soil lichens (Woodmansee 1979).

TABLE 2. Characteristics of Soils at Remediation Sites

Location	Texture	pH	P (ppm)	K (ppm)	Total N (ppm)	% Organic Carbon	Cation Exchange Capacity meq/100 g	% Sand	% Silt	% Clay
DC-12	Sandy loam	8.52	9.25	421	252	0.252	9.35	71.7	23.3	4.98
DC-16	Loamy sand	8.45	4.25	241	138	0.145	7.12	69.4	25.6	4.95
DC-18	Sandy loam	8.70	2.50	117	190	0.158	8.25	37.1	57.3	5.60
DC-20	Loamy sand	8.22	7.25	276	172	0.188	6.68	76.0	19.9	4.02
DC-7/8	Sand	7.85	3.00	268	108	0.142	6.12	86.1	9.4	4.42
NSTF Borrow Pit	Loamy sand	8.62	13.5	210	192	0.215	7.72	78.9	17.5	3.65
NSTF Boxcuts	Loamy sand	8.31	24.7	213	316	0.457	8.40	76.7	19.4	3.90
NSTF Generator Area	Loamy sand	7.95	35.0	214	448	0.548	10.5	74.2	21.2	4.52
NSTF Vent Area	Loamy sand	8.00	47.2	206	485	0.675	8.72	78.9	16.4	4.62
NSTF Water Line West	Loamy sand	7.97	31.7	376	540	0.803	8.92	77.1	18.4	4.45
RRL-10	Sandy loam	8.48	7.75	526	220	0.208	10.35	66.5	26.4	7.08
RRL-7	Sandy loam	8.20	7.00	435	265	0.370	8.75	73.2	21.9	4.85

TABLE 3. Concentrations (ppm) of Minerals in Plants and in Solution Sufficient to Support Growth in Sand[a]

Mineral	Plant Concentration	Solution Concentration
Carbon	450,000	N/A
Oxygen	450,000	N/A
Hydrogen	70,000	N/A
Nitrogen	10,000	210
Potassium	9,000	195
Calcium	7,000	200
Magnesium	1,500	35
Phosphorus	1,500	30
Sulfur	800	50
Iron	70	5.5
Chlorine	70	3.5
Manganese	40	0.5
Boron	8	0.05
Zinc	8	0.01
Copper	3	0.01
Molybdenum	0.1	0.005

(a)Bradshaw and Chadwick 1980.

As can be seen by comparing Table 3 to the soils data from the remediation sites (Table 2), soil concentrations of phosphorus and nitrogen on most of the remediation sites were well below concentrations necessary to support growth of most plants, except those tolerant of low nutrient levels. Furthermore, concentrations of these nutrients on remediation sites were below the concentrations found in undisturbed Hanford soils of similar textural class (compare values in Table 3 with those in Table 4). Although Sandberg's bluegrass and bottlebrush squirreltail are apparently tolerant of low nutrient levels, it is not known whether this tolerance is a function of the plants' association with mycorrhizal fungi. These fungi are known to be symbionts with many plants endemic to nutrient-poor soils, and assist the plants in taking up water and scarce nutrients.

Besides providing a nutrient pool, soils also constitute a medium for retaining precipitation. The capability of soils to store water depends largely on the soil's texture, with coarser soils holding less water than finer soils. However, the

TABLE 4. Characteristics of Undisturbed Soils on the Hanford Site[a]

Texture	Sand[b]	Silt[b]	Clay[b]	pH	CEC[c]	Total N[d]	P[d]	K[d]	Organic C[b]
Sand	89.36	7.27	3.34	7.76	5.98	180	6	280	0.171
Loamy sand	81.82	13.83	4.33	7.70	6.07	233	8	278	0.242
Sandy loam	60.31	34.17	5.54	7.94	8.84	307	10	398	0.354
Loam	48.65	42.15	9.25	7.55	11.15	500	13	655	0.650
Silt loam	28.55	64.69	6.80	8.08	13.21	600	23	798	0.678
Worldwide[e]	20	55	25	7.2	24	2000	30	400	7

(a)Most data from Brandt et al. 1990a.
(b)Percentage.
(c)Cation exchange capacity, in meq/100 g.
(d)In ppm.
(e)Data from Bradshaw and Chadwick 1980.

amount of water available to plants is not equal to the amount stored. Available water capacity is the difference between the amount of water that can be held by the soil against gravity (i.e., field capacity) and the amount held by the soil when plants begin to wilt (i.e., wilting point). Thus, although sandy loam has less than half the field capacity of clay loams, plant-available water is actually greater in the sandy loam (Table 5).

Organic matter content of soils also affects moisture-holding capacity directly through absorption and surface-tension effects and indirectly through effects on soil structure. Structure is the arrangement of primary soil particles and humic materials into secondary particles or aggregates. Well-developed soils are aggregated into crumbs with intervening spaces that may be filled with air or water and from which plants obtain nutrients and water. Lack of aggregates lowers water infiltration and increases crusting of the soil surface in finer-textured soils, both of which inhibit plant establishment. Formation of surficial crusts was apparent at sites RRL-10 and DB-15; the remaining coarse-textured boreholes lacked sufficient organic matter to provide the necessary soil structure and moisture-holding capacity.

Additional samples of surface soils were collected from the remediation sites and subjected to plant growth bioassays using barley (*Hordeum vulgare*) and alfalfa (*Medicago sativa*) under controlled environmental conditions (greenhouse). All treatments received fertilizer and water sufficient to keep the soils wet throughout the bioassay period. Plants were then harvested and above-ground biomass of plants determined. These bioassays served to determine if residual

TABLE 5. Water Retention and Availability Versus Soil Texture[a]

Soil type	Field capacity[b]	Wilting point[b]	Available water[c]
Sand	6.7	1.8	1.98
Sandy loam	19.8	7.9	4.75
Silt loam	35.3	12.7	7.05
Clay loam	30.1	16.3	4.15

(a) Bradshaw and Chadwick 1980.
(b) Percentage water.
(c) In cm water, assuming 30-cm rooting depth.

herbicides in the soil occurred in sufficient quantities to adversely affect plant growth. Soil samples from all sites where salvaged borehole material had been applied exhibited strong herbicidal effects, as did DC-12 and DC-16.

TASK 3: DEVELOPMENT OF REMEDIATION METHODS

The objective of this task was to identify methods for remediating sites identified under Task 1. Potentially suitable remediation methods were required that would address the critical issues of minimal water-holding capacity and herbicide activity on the NSTF box cuts, the NSTF generator/ventilation shaft, NSTF borrow pit, DC-12, and DC-16; the poor water holding capacities of RRL-7; and the soil crusts formed on RRL-10 and DB-15. Although some soils from DC-7/8 exhibited herbicidal activity, approximately half the site supported vegetation, so disturbance caused by remediation needed to be minimal. Plant growth failures on the NSTF waterline and DC-20 were attributed to the low water-holding capacity of the gravely soils on those sites (gravels were removed from samples reported in Table 2), but both sites supported patches of vegetation, so disturbance of those sites was also to be kept minimal.

The most effective treatment for poor water-holding capacity alone or in combination with nutrient deficiencies is the incorporation of biologically active organic material, such as sewage sludges or composts (Brandt and Hendrickson 1991). However, monitoring and permitting requirements limit the ease with which sludges may be used (Brandt and Hendrickson 1990). Benefits of compost amendments derive from the compost's structure, organic carbon pool, nutrient content and form, and microbiological innocula. The relative contributions of each to soil characteristics and plant growth will vary with compost characteristics, which depend on the types of materials and bulking agents used. Composts provide a large amount of degraded organic matter, which may improve the friability of fine-textured soils and the moisture-holding capacity of coarse-textured soils (Bradshaw and Chadwick 1980). Physical characteristics of soils generally may be altered by additions of 25% compost by volume. Nutrients compose relatively little of compost dry matter; however, because composts are based on plant or animal wastes, they contain the full range of plant macro- and micronutrients in proportions generally suitable to support plant growth.

Remediation treatments for seedbeds were therefore focused on relieving nutrient and moisture-holding capacity constraints, and covering herbicide-contaminated soils with appropriate topsoil. After discussions with the U.S Department of Energy Richland Field Office and Kaiser Engineers Hanford, soils from the McGee Ranch pit were selected as being both suitable and cost-efficient as a topsoil. Compost was used as a soil amendment on some of the sites (Table 6), as was a 10:20:10 (N:P:K) fertilizer and wood chips. The latter serves as a long-term source of carbon to sustain the soil biota and promote nutrient cycling. The revegetation contractor (Bentz Fence Co.) proposed use of a Brillion grass seeder on all sites, which was accepted as the preferred seeding alternative. Also, composts from a commercial cattle feedlot were obtained.

Remediation work began on November 8 and was completed by December 8, 1991. Soils, wood chips, fertilizer, and compost were stockpiled at the NSTF Borrow Pit, where they were mixed in appropriate proportions and hauled to each site. After seeding, all sites were hydromulched using 100% wood fiber with a 3% tacking agent, applied at a rate of 1600 kg/ha.

TASK 4: EVALUATION OF REMEDIATION

Remediation work was monitored by PNL as it progressed. Performance of remediation was conducted to specifications. Where seedbed treatments consisted only of compost and fertilizer, disking failed to incorporate the compost with the underlying soil. Consequently, the top 7.5 to 15 cm (3 to 6 in.) of those sites consists of almost pure compost. Compost was generally not mature and had not received a minimum 120-day curing period. The use of uncured and immature composts is expected to result in seed damage, and would tie up nitrogen in the composts, making it unavailable to the plants. The latter effect was counteracted by the addition of fertilizer to all composts. However, the continued composting action was expected to cause seed mortality in those sites where compost was not mixed with soil.

Vegetation emergence and growth was evaluated at each remediation site. Sites were visually examined at the beginning of each month following completion of reseeding to determine germination of seeds. The first seeded plants began to emerge during January 1992; consequently, quantitative

TABLE 6. Remediation Treatments

Location	Seedbed Treatment	Seeding Method	Species Seeded	Seeding Rate[a]	Acreage
DB-15	3-in. compost disked into existing seedbed. Follow with cultivator or harrow	Brillion seeder	*Poa sandbergii* *Stipa comata* *Sitanion hystrix* *Melilotus alba*	13 3 3 1.5	0.6
DC-12	6-in. McGee Ranch soil with 25% compost by volume. Follow with cultivator or harrow.	Brillion seeder	*Poa sandbergii* *Sitanion hystrix* *Melilotus alba*	13 3 1.5	0.7
DC-16	3-in. compost disked into existing seedbed.	Brillion seeder	*Poa sandbergii* *Sitanion hystrix* *Melilotus alba*	13 3 1.5	3.8
DC-18	15:30:15 fertilizer applied at 40 lb N/acre disked into existing seedbed. Follow with cultivator or harrow.	Brillion seeder	*Poa sandbergii* *Stipa comata* *Sitanion hystrix* *Melilotus alba*	13 3 3 1.5	2.6
DC-20	15:30:15 fertilizer applied at 40 lb N/acre disked into existing seedbed. Follow with cultivator or harrow.	Brillion seeder	*Poa sandbergii* *Sitanion hystrix* *Melilotus alba*	13 3 1.5	3.8
DC-7/8 (west half of pad)	Broadcast a 15:30:15 fertilizer applied at 20 lb N/acre to WEST HALF of pad area.	Brillion seeder	*Poa sandbergii* *Stipa comata* *Sitanion hystrix* *Melilotus alba*	13 3 3 1.5	0.6

TABLE 6 (Cont'd)

Location	Seedbed Treatment	Seeding Method	Species Seeded	Seeding Rate[a]	Acreage
RRL-7	6-in. McGee Ranch soil with 5% wood chips by volume and 15:30:15 fertilizer applied at 75 lb N/acre. Follow with cultivator or harrow	Brillion seeder	*Poa sandbergii* *Sitanion hystrix* *Melilotus alba*	13 6 1.5	0.7
RRL-10	3-in. compost disked into existing seedbed. Follow with cultivator or harrow.	Brillion seeder	*Poa sandbergii*	12	0.5
NSTF Water Line West of Highway	None	Brillion seeder	*Poa sandbergii* *Sitanion hystrix* *Melilotus alba*	13 3 1.5	7.2
NSTF Borrow Pit	6-in. McGee Ranch soil with 25% compost by volume. Follow with cultivator or harrow	Brillion seeder	*Poa sandbergii* *Melilotus alba*	13 1.5	4.8
NSTF Box Cuts, Ventilation Shaft, and Generator Areas	6-in. McGee Ranch soil with 5% wood chips by volume, and a 15:30:15 fertilizer applied at 75 lb N/acre. Follow with cultivator or harrow.	Brillion seeder	*Poa sandbergii*	13	7

(a) lb/acre

examinations were begun during the first week of February 1992 and repeated during March. Quantitative examinations provided estimates of plant density for all species found on each remediated site. Density was determined by counting all individual plants occurring within 0.25-m^2 sampling frames, which were distributed at 2-m intervals along a tape. The tape was laid on each site to run from one corner of the site to the opposite corner to maximize the number of samples taken from the site, up to a maximum of 51 samples (i.e., from a 100-m tape).

Statistics on plant emergence are shown in Table 7. Seeds of all species continued to germinate during the 2 months of evaluation. Average densities of seeded species far exceeded levels obtained during any of the previous years of BWIP reclamation.

Sites differed significantly in the average density of seeded grasses they supported (Sandberg's bluegrass $F_{14,1391} = 2.106$, $P=0.0095$; bottlebrush squirreltail $F_{7,895} = 8.073$, $P<0.001$). Plant density differences among sites were evaluated in relation to the seedbed treatments each site received during remediation using Analysis of Covariance to remove the effects of sampling date on plant density estimates. Analyses were limited to Sandberg's bluegrass and Russian thistle, because these were by far the most common seeded and invading species found on the sites.

Seedbed treatments significantly affected density of both Sandberg's bluegrass and Russian thistle (Table 8). Sandberg's bluegrass density was highest overall on sites where the seedbed treatment consisted only of fertilizer disked into the soil (DC-7/8, DC-20, and DC-18) and McGee Ranch soil-plus-compost treatments (NSTF Borrow Pit and DC-12). Grass density was lowest on the compost-only treatment (DC-16, RRL-10, and DB-15) (Figure 1). The increase in plant density over time remained constant among treatments, indicating that the lower-density sites had not caught up with the faster-emerging sites by the end of March. Most of the sites involving McGee Ranch soils, compost, and wood chips were located on Gable Mountain on north-facing slopes. Soil and air

TABLE 7. Mean and Standard Error of Plant Densities/m^2 on Remediated Sites

	Sandberg's bluegrass	Bottlebrush Squirreltail	Needle-and-thread grass	White Clover	Russian thistle	Cheatgrass
February						
Mean	82.0	0.100	2.17	0	58.0	3.10
Std. Error	1.6	0.010	0.090	0	1.7	0.12
March						
Mean	211	4.16	1.30	7.40	214	9.52
Std. Error	3.7	0.11	0.058	0.84	4.1	0.50

temperatures at these sites will be lower than at the remaining sites because of the higher elevation and northern orientation and were expected to delay germination.

Russian thistle density was highest on the sites that received minimal surface disturbance [i.e., no seedbed treatment at all (the NSTF water line) and fertilizer disked into the seedbed]. The remaining treatments had little effect on thistle density. This result suggests that the number of Russian thistle to emerge from a these sites depends on the degree to which the soil was disturbed and the depth at which the Russian thistle seeds already in the soil were buried. Also, the sites receiving soil treatments did not have much Russian thistle cover before remediation, especially in comparison to the water line, DC-7/8, and DC-20. The seed pool for this species was consequently smaller in the former sites.

TABLE 8. Analysis of Covariance: Seedbed Treatment Effects on Plant Density

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Sandberg's bluegrass					
Treatment	5	510262.711	102052.542	18.315	.0001
Date	1	360194.304	360194.304	64.642	.0001
Residual	1416	7890173.361	5572.156		
Russian thistle					
Treatment	5	2842326.705	568465.341	106.730	.0001
Date	1	498161.300	498161.300	93.530	.0001
Residual	1416	7541924.655	5326.218		

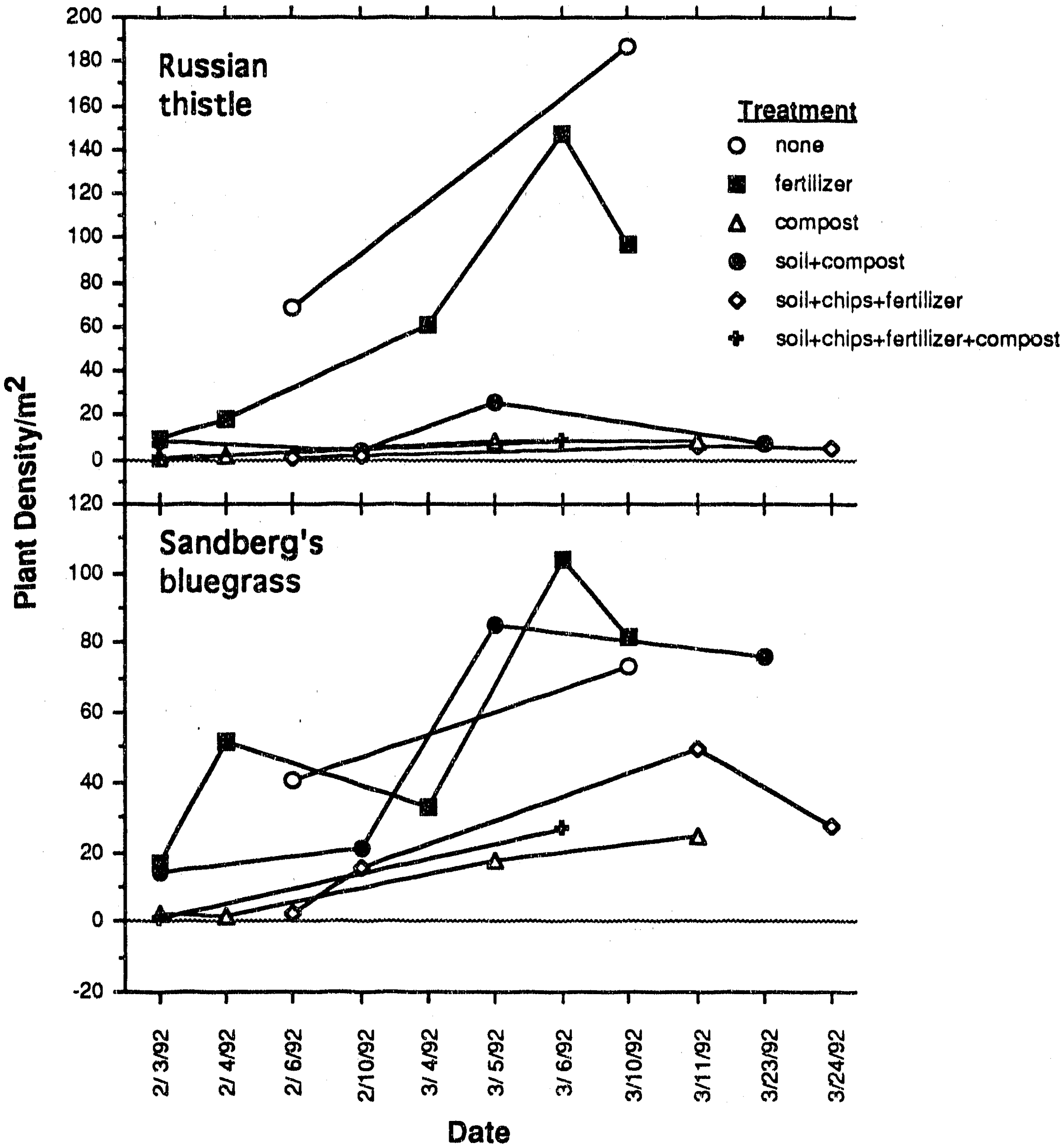

FIGURE 1. Trends in Density of Sandberg's Bluegrass and Russian Thistle on Remediation Sites

CONCLUSION

At the end of March 1992, growth of vegetation on remediation sites was well above that needed to meet the reclamation objectives for these sites. All sites supported grass far in excess of the numbers found after their first seeding. This exceptional growth may be attributed in part to the treatments applied during remediation, and to the exceptionally mild and wet winter. Should conditions remain mild and moist, the prospects for continued performance are excellent.

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M. J. Graham
R. L. Skaggs
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P. C. Hays (last)

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