REVEGETATION OF A MINE TAILINGS IMPOUNDMENT USING MUNICIPAL BIOSOLIDS IN A SEMI-ARID ENVIRONMENT

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ABSTRACT

Five separate test sites were established in 1994 to evaluate the use of municipal sewage sludge as a soil amendment and conditioner (hereafter referred to as "biosolids") on the Kennecott Utah Copper Corporation's tailings impoundment near Magna, Utah. Each site was divided into 16 test plots to evaluate four replications of the four rates of biosolids addition and incorporation into the tailings. The sites were monitored for potential leaching of total heavy metals as required under 40 CFR 503, agronomic properties, total metals, extractable metals, plant tissue analysis for heavy metals, biomass production, percent cover and plant species diversity.

This paper presents the results through the second year of the project to include a comparison of soils and vegetation properties versus changes in the properties after two growing seasons. All agronomic properties of the tailings showed continued improvement following the initial biosolids addition. Significant improvements were seen when comparing the control plots to all treated plots. A statistically significant continued improvement in biomass production and percent cover by plant species occurred for all biosolids application rates when compared to the control plots. These important long-term reclamation objectives are related to the increase in biodiversity as well as to the amount of dead vegetation (winter rye) left from the 1995 growing season.

Key words: *biosolids, revegetation, leaching, mine tailings*

INTRODUCTION

The biosolids demonstration project is a cooperative effort between Kennecott Utah Copper Corporation (KUCC), the Department of Mining Engineering of the University of Utah, and the Central Valley Water Reclamation Facility (CVWRF). The purpose of this project is to evaluate the enhancement of vegetative growth after a one-time application of biosolids to the slopes of the KUCC tailings impoundment, near Magna, Utah. Anaerobically digested (Class B) biosolids from the CVWRF were used as biosolids. The Magna Wastewater District also provided aerobically treated (Class B) biosolids for one of the test sites. The test site tailings were sampled for metals and agronomic properties before and after the application of biosolids. The sites were and will be evaluated at 1, 2, 3, 5, and 10 years after the initial application for chemical and agronomic properties, biomass production, and above-ground species diversity.

Kennecott Utah Copper Corporation's goals in managing the tailings impoundment are the following: 1) dust control for purposes of complying with air quality permits, 2) erosion control and embankment stabilization, and 3) re-establishing native vegetation on a long-term basis and improving visual appearance. Vegetation is the most cost-effective and permanent method of accomplishing these goals.

Tailings amended with chemical fertilizers, unlike tailings amended with biosolids, require extensive time periods, often as long as 20 years, for the buildup of microbial populations, which is an indicator of biological activity in the soil/tailings profile as well as a significant indicator of long-term reclamation success (Segal and Mancinelli, 1987). The use of biosolids is attractive because of the use of two waste products to establish permanent plant communities. Extensive research has shown that stabilized municipal biosolids are an excellent tailings amendment and chemical fertilizer substitute. Successful establishment of forage species has occurred in the past directly on degraded land amended with biosolids (Munshower, 1994).

BIOSOLIDS – CHARACTERISTICS

The CVWRF biosolids—as a dry belt filter press cake—were analyzed for the 40 CFR 503 regulated metals before and during application to the impoundment. Both analyses were based on average and maximum test results from January 3 to March 1, 1994. These analyses are given in another paper (McNearny, 1997). Similar analyses were performed on the Magna biosolids. The Magna biosolids test results are also available in the other paper. The biosolids did not exceed the 40 CFR 503 mandated limits.

EXPERIMENTAL DESIGN

The experimental design consists of single-factor linear design that utilizes randomized complete plots for all test sites. This design was chosen because of its suitability in reducing experimental error due to known sources of variation, e.g., variation in pH or other properties of the tailings across each test site. Each test site has been divided into plots of approximately one acre each. The width of each plot was kept close to 100 feet to facilitate biosolids application. The number of plots in each site is in a multiple of four. Thus, there generally are an equal number of test plots for each application rate per site. Each test plot received one of the different application rates of biosolids, applied on a random basis.

Project Site Descriptions and Locations

The KUCC tailings pond covers an area of approximately 5600 acres. All project sites are located on the slopes of the tailings impoundment. The property is fenced and locked from public access. The depth to the first major aquifer is 230 feet.

Four sites (Sites No. 1, 2, 3, and 3B) were established on the northwestern slope of the impoundment, facing the Great Salt Lake. Site No. 4 was north-facing. The slopes of the test sites vary from a minimum of 20 to 1 to a maximum of 7 to 1. Each site was divided into approximately 16 plots of 0.5 to one acre each, giving a total of approximately 100 plots for the six sites.

Seeding

The sites were seeded along the contour in the spring of 1995 with a mixture of perennials and legumes (Table 1) using a drill seeder.

TAILINGS SAMPLES

To determine which tailings properties could be used to identify conditions which support growth and which are inhibiting, baseline tailings samples were taken in 1994. Baseline monitoring was required to assess the pre-reclamation environmental conditions of the area and initial tailings variability. Monitoring included detailed sampling and testing to determine the physical properties and chemical characteristics of the tailings. The tailings were also analyzed after the application of biosolids and amendments.

Baseline tailings samples from within the top six inches of depth were tested for agronomic properties in the summer of 1994. The samples were composited across the four replicate plots according to the biosolids application rate. Thus, each test site provided four composited samples. Each sample was split into two, one of which was held in storage for retesting if necessary, and the other tested at Utah State University, Logan, Utah. Post-application agronomic sampling runs were made in December 1994, July 1995, and July 1996. The 1996 agronomic test results are reported in Table 2.

BIOMONITORING SAMPLING

Vegetation enhancement was compared with the control plots for each test site, and its success was determined as a function of measured biomass production, species diversity, and percent cover measured by one transect across the plot using the line intercept method (Chambers and Brown, 1983). Within each plot, vegetation was identified by transect and bagged by individual species. Species diversity was calculated directly from the field notes and by sample collection. Biomass sampling and species diversity transects were performed in the summers of 1995 and 1996. For biomass production, plant species was harvested from the test plot, dried, and weighed to obtain total above-ground biomass and species-weighted biomass results.

Plant Production (Biomass)

Above-ground biomass estimates were obtained by hand-clipping five randomly located 1-m-diameter circular quadrants from each plot during the summer of 1996. Plants within each quadrant were clipped approximately 1 cm above the tailings surface, bagged, and returned to the laboratory. There they were dried to constant weight in a forced-air oven at 140 ^{o}F for 24 hours and weighed to obtain dry weights.

Percent Cover

Plant areal cover was estimated by species for all the plots during the summer of 1996. Areal cover is defined as the proportion of the ground occupied by a perpendicular projection of the aerial parts of individuals of the species under consideration. A line intercept method of plant cover estimation was used (Chambers and Brown, 1983) on all plots. A 100-foot tape was stretched roughly parallel to the long axis of each plot along the embankment face. The percent plant cover was estimated, by species, using a 4-inch-diameter, 4-foot-long, cross-wire sighting tube placed at one-foot intervals along each transect. The amount of the tailings surface covered by rock was also estimated. Thus, 100 readings were taken for each plot and averaged. Cover estimates were made by species.

Species Distribution (Diversity)

Frequency data provide information on how species are distributed within a plant community or, in this case, across the revegetation plots or within individual treatments. The frequency is the percentage of observations taken through the sighting tube in which a given species occurred. Observations included the percent ground cover of each species. The frequencies of the observations were then averaged for each test plot.

RESULTS AND DISCUSSION

Agronomic Test Results

Table 2 presents the results of the agronomic testing program from the baseline tests to the most recent tests performed on samples taken in June 1996. The results in Table 2 are average values of all plots for each test site. Generally, the values have stabilized, indicating that nutrient cycling has been initiated in the biosolids-amended sites. One exception, however, is the percent organic matter, which has increased significantly. This is not surprising, given the significant increase in dead and decaying vegetation (mostly winter rye) on the biosolids-amended sites.

BIOMONITORING RESULTS AND DISCUSSION

Plant Production (Biomass)

Statistically significant differential biomass responses were observed in the 1996 sampling program on all test plots where biosolids were added when compared to the control plots (Table 3 and Figure 1).

Test Site No. 2 had the highest level of biomass production, followed by Test Site No. 1, followed by Test Site No. 3, followed by Test Site No. 4, followed by Test Site No. 3B. The lower mean level of biomass production for Test Site No. 3 may have been due to higher rates of nitrogen utilization by microbes to mineralize the additional carbon supplied by the wood residues. The aerobically treated Magna biosolids had typically lower levels of nitrogen than the anaerobically-digested CVWRF biosolids, which contributed to the relatively low biomass production in Test Site No. 3B when compared to the other sites where biosolids were added.

This observation is expected, as fewer nutrients are available in aerobically treated biosolids. From Figure 1, one can conclude that biomass production increased significantly from the controls with an increase in the biosolids application rate, regardless of the site. Site No. 2 had the highest production consistently, with the 30-dry-ton/acre application producing the greatest amount of biomass. Generally the biomass production for the 10-, 20-, and 30-dry-ton/acre application rates was significantly greater than the controls. There was no significant difference between the 10- and 20-dry-ton/acre application rates. The 30-dry-ton/acre application rate had a significantly higher biomass production than the 10- and 20-dry-ton/acre application rates.

1996 Percent Cover Data

All test species were examined for any kind of correlation between biosolids application rate and percent cover using either the Pearson product moment correlation or the Spearman rank order correlation test at a significance level of 5%. Percent cover of all the species planted increased significantly with increasing biosolids application rate (Figure 2), while it did not change significantly with different kinds of biosolids applied (Table 4). Interestingly, the lowest percent cover occurred in Site No. 2, which had the highest biomass production.

Comparison of Percent Cover Between 1995 and 1996

Percent cover of all species within each amended test site, except test Sites Nos. 2 and 3 increased significantly (12.2%) from 1995 to 1996 (Table 5).

Comparison of Percent Cover by Site

The total vegetation percent cover increased significantly from 1995 to 1996 at Test Sites Nos. 1 and 4. Test Site No. 3B also had an increase in percent cover at the 10-, 20- and 30-dry-ton/acre application rates. Site No. 3 had a significant increase in percent cover at the 10-dry-ton/acre application rate. Site No. 2 had no increase in percent cover from 1995 to 1996.

Comparison of Percent Cover by Biosolids Application Rate

Vegetation cover increased significantly at each biosolids application rate when compared to the control (Table 6), with the largest increases in the 20- and 30-dry-tons/acre application rates and a smaller, but significant, increase in coverage at the 10-dry-tons/acre application rate. Biosolids application thus has been shown to accelerate the reclamation process and shorten the time to establish a self-sustaining ecosystem at the tailings impoundment (Segal and Mancinelli, 1987).

1996 Diversity Data Analysis

After the second growing season, a positive growth response of planted test species to biosolids addition was still apparent (Figure 3).

In 1996, sheep fescue exhibited the greatest overall mean percent cover (19 %), followed by dead vegetation (16 %), and tall wheat grass (6 %). There was a statistically significant increase in percent cover with increasing biosolids application rate for sheep fescue, dead vegetation, and tall wheat grass, especially between the control and the biosolids application rate of 10 dry tons/acre. In contrast, the percent coverage did not increase significantly between 1995 and 1996 with a biosolids application rate greater than 10 dry tons/acre. Other test species did not display any statistically significant difference in the percent cover, including clover and kochia, which is an invasive weed.

The higher percentages of dead vegetation are not surprising, given the extremely large amounts of winter rye produced in 1995. The percentage of dead vegetation should decrease in the coming years as the decay process continues. The shifts in percent cover indicate a change in the vegetation community with time. This is expected, as the nurse crop of winter rye is gradually being replaced by the more desirable reclamation species, with the largest increases in sheep fescue and tall wheat grass and a smaller increase in the legumes.

Comparison of Diversity Between 1995 and 1996

From Table 7 and Figure 4, one can tell that there are now measurable amounts of an additional species (clover) in 1996 compared to 1995. The percent cover by different species is more evenly distributed in 1996 than in 1995, when winter rye had 67% of the total growth; the dominant plant in 1996 is sheep fescue at 37% of the total growth .

Significant increases occurred in sheep fescue, tall wheat grass, and dead vegetation. There was a significant decrease in winter rye. Both alfalfa and clover increased measurably. The total number of invasive weeds remained approximately the same.

CONCLUSIONS

Continued data collection from surface tailing samples indicates that there is continuing improvement of the tailings agronome properties.

The dominant species found on the test sites was sheep fescue. A shift in the plant community has occurred which indicates that the more desirable reclamation species are increasing. The percent total cover for all sites where biosolids were added has increased significantly.

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Table 1. Seed mix.

Common Name	Scientific Name	PLS (lb./acre)
Stabilization Cover Crop:		
Winter rye	*Secale cereale*	30
Perennial Mix:		
Yellow sweetclover	*Mililotus officinalis*	3
Tall wheatgrass	*Agropyron elongatum*	3
Sheep fescue	*Festuca ovina*	3
Alfalfa (Ranger)	*Medicago sativa*	3
Winter rye	*Secale cereale*	10

Table 2. Agronomic properties of the tailings and tailings-biosolids mix.

				Extractable										
Tailings, Baseline Measurements (mg/kg), September 1994														
pH	%OM	NO^{3}-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
6.8	0.23	0.01	3.8	131	549	204	82	0.10	73	16	5	0.3	0.1	2
Tailings-Biosolids Misx, December 1994 (mg/kg)														
pH	%OM	NO^{3}-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
6.7	0.83*	111*	35*	142	893*	24*	28	nd	53	15	2	0.1	0.7	4.6*
Tailings-Biosolid Mix, June 1995 (mg/kg)														
pH	%OM	NO^{3}-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
7.1	0.39	-----	11	120	273*	24*	28	nd	53	15	2	0.1	0.7	4.0*
Tailings-Biosolid Mix, June 1995(mg/kg)														
pH	%OM	NO^{3}-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
6.9	1.13*	-----	24*	168	697*	147	101	<0.1	65	15	5	0.3	0.9	5.0*

* designates a statistical difference from the baseline value at a = 0.05
nd designates no detection.

Table 3. Comparison of mean biomass results (g/acre) by additional amendment and by biosolids application rates within each test site (1996).

Appl. Rate (dry tons/acre)	Site No. 1 (With $CaCO_3$)	Site No. 2 (biosolids only)	Site No. 3 (with wood)	Site No. 4 (Magna biosolids)	Site No. 4 (biosolids)	Mean
0	20	10	45	6	20	20
10	124	141	89	77	101	106
20	120	144	121	108	138	126
30	172	305	134	170	146	185
Mean	109	150	97	90	101	

Table 4. Comparison of percent cover of all species by additional amendment and by biosolid.

Appl. Rate (drytons/acre)	Site No. 1 (with $CaCO_3$)	Site No. 2 (biosolids only)	Site No. 3 (with wood)	Site No. 3B (Magna biosolids)	Site No. 4 (biosolids)	Mean
0	6.1%	8.8%	22.9%	3.7%	12.1%	10.7%
10	57.2%	40.4%	69.0%	38.9%	73.2%	55.7%
20	71.8%	57.9%	54.4%	69.1%	83.8%	67.4%
30	79.7%	71.2%	70.0%	74.4%	75.9%	74.2%
Mean	53.7%	44.6%	54.1%	46.5%	61.2%	

Table 5. Change in percent cover of all species by additional amendment and by biosolds application rate within each test site between 1995 and 1996.

	Year (change)	0	10	20	30	Mean increase of amended sites
Site No. 1 (With $CaCO_3$)	1995	3.8%	37.3%	61.9%	3.8%	
	1996	6.1%	57.2%	71.8%	49.5%	
	(increased)	2.3%	19.9%	9.9%	30.2%	20.2%
Site No. 2 (biosolids only)	1995	6.9%	46.8%	57.7%	65.1%	
	1996	8.8%	40.4%	57.9%	71.2%	
	(no increase)	1.9%	-6.4%	0.2%	6.1%	0.0%
Site No. 3 (with wood chips)	1995	16.0%	53.0%	54.5%	74.1%	
	1996	22.9%	69.0%	54.4%	70.0%	
	(increased)	6.9%	16.0%	-0.1%	-4.1%	3.9%
Site No. 3B (Magna biosolids)	1995	2.5%	26.2%	53.5%	54.1%	
	1996	3.7%	38.9%	69.1%	74.4%	
	(increased)	1.2%	12.7%	15.6%	20.3%	16.2%
Site No. 4 (biosolids only)	1995	6.9%	46.8%	57.7%	65.1%	
	1996	12.1%	73.2%	83.3%	75.9%	
	(increased)	5.2%	26.4%	26.1%	10.8%	21.1%
Mean increase by application rate		3.5%	13.7%	10.3%	12.7%	**12.2%**

Table 6. Comparison of 1996 percent cover of different species and inert matter by biosolids application rates within each test site.

Biosolid rate Tons/acre	Sheep Fescue	Dead Veg	Legumes	Tall Wheat Grass	Winter Rye	Weeds	Rock	Clover	Total
0	2.8%	1.4%	2.2%	2.9%	0.2%	1.0%	0.3%	0.0%	10.7%
10	22.4%	18.7%	0.8%	5.9%	2.7%	5.2%	0.0%	0.0%	55.7%
20	25.6%	21.5%	1.5%	7.5%	2.3%	9.0%	0.0%	0.0%	67.4%
30	27.0%	23.2%	0.4%	9.7%	5.3%	8.5%	0.1%	0.3%	74.2%
Mean	19.4%	16.2%	1.2%	6.5%	2.6%	5.9%	0.1%	0.1%	

Table 7. Comparison of percent coverage of different species and dead vegetation by biosolds application rates within each test site between 1995 and 1996.

Biosolid rate, t/acre	0		10		20		30		Mean	
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Sheep fescue	1.7%	2.8%	6.3%	22.4%	14.7%	25.6%	7.6%	27.0%	7.6%	19.4%
Dead Veg	~0%	1.4%	~0%	18.7%	~0%	21.5%	~0%	23.2%	~0%	16.2%
Legumes	1.4%	2.2%	0.3%	0.8%	0.5%	1.5%	0.9%	0.4%	0.8%	1.2%
Tall Wheat Grass	0.3%	2.9%	1.2%	5.9%	1.8%	7.5%	0.6%	9.7%	1.0%	6.5%
Winter Rye	2.5%	0.2%	26.2%	2.7%	34.6%	2.3%	49.1%	5.3%	28.1%	2.6%
Weeds	1.4%	1.0%	6.9%	5.2%	5.2%	9.0%	4.6%	8.5%	4.5%	5.9%
Clover	~0%	~0%	~0%	~0%	~0%	~0%	~0%	~0%	~0%	0.1%
Total	7.3%	10.7%	40.8%	55.7%	56.9%	67.4%	62.8%	74.2%	42.0%	52.0%
Increase		3.4%		14.9%		10.5%		11.5%		10.1%

Figure 1a. Site-specific biomass production by application rate (1996).

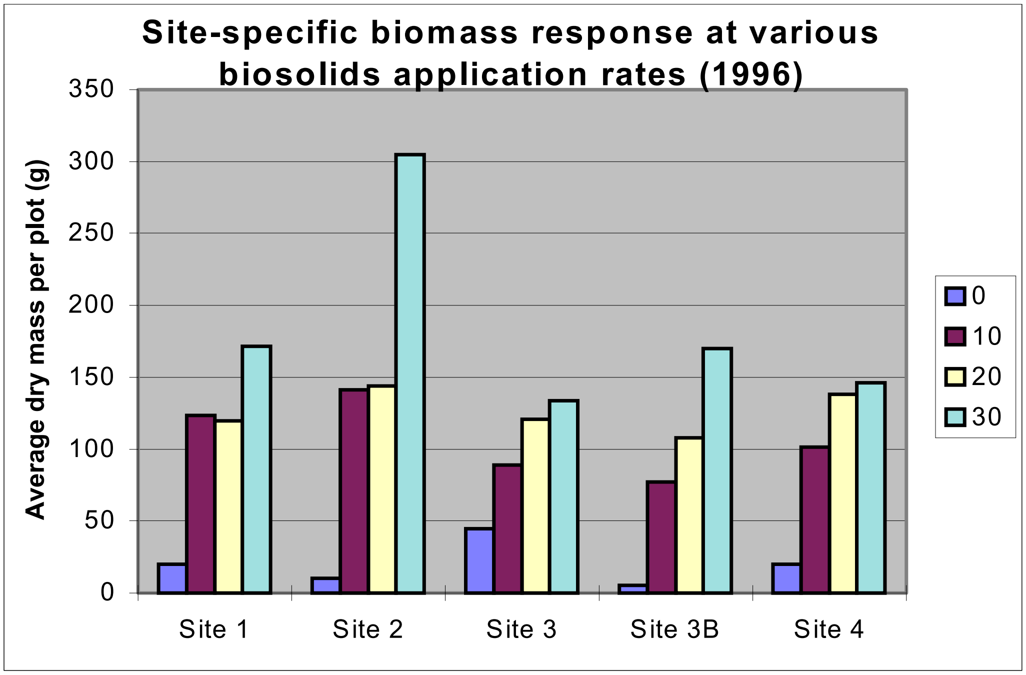

Figure 1b. Application-specific biomass production by site (1996).

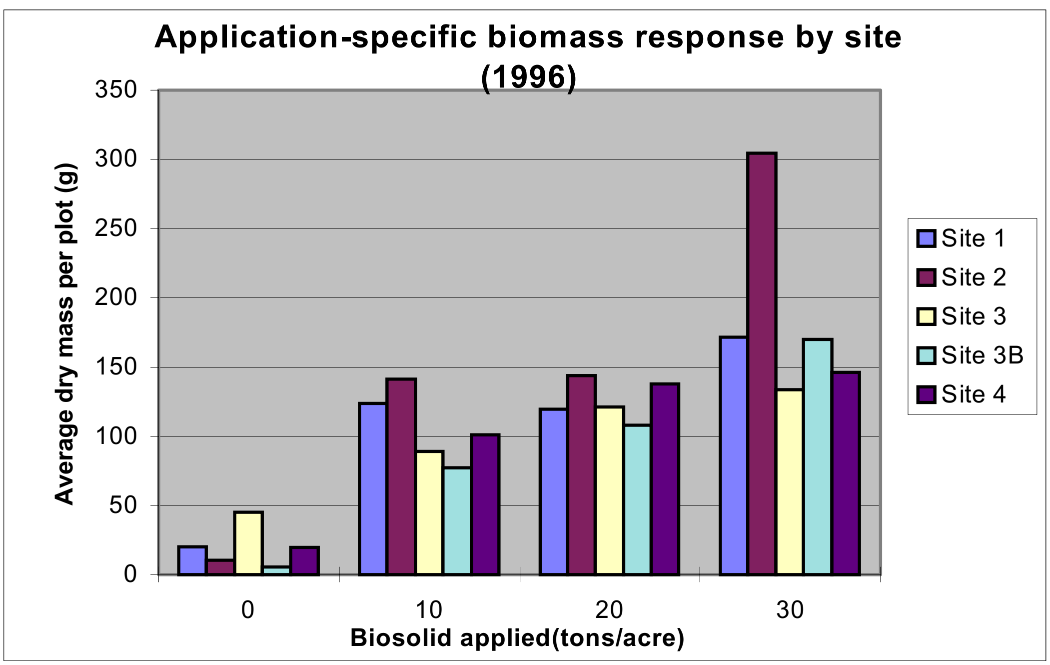

Figure 2. Application-specific percent cover by site.

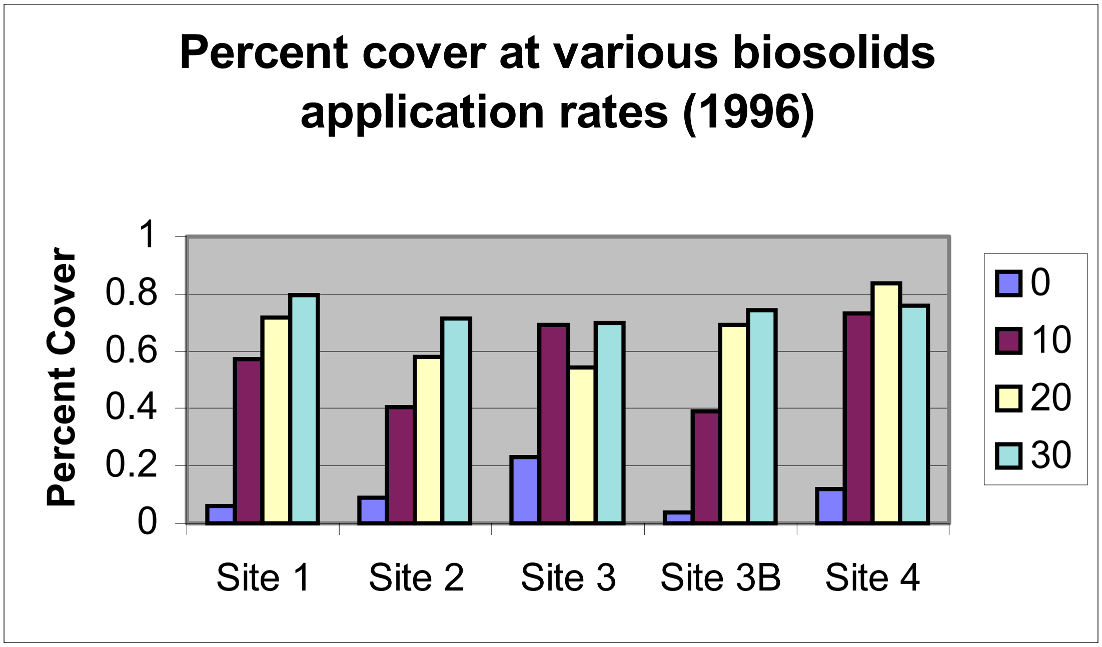

Figure 3. Percent cover at various biosolids rates (1996).

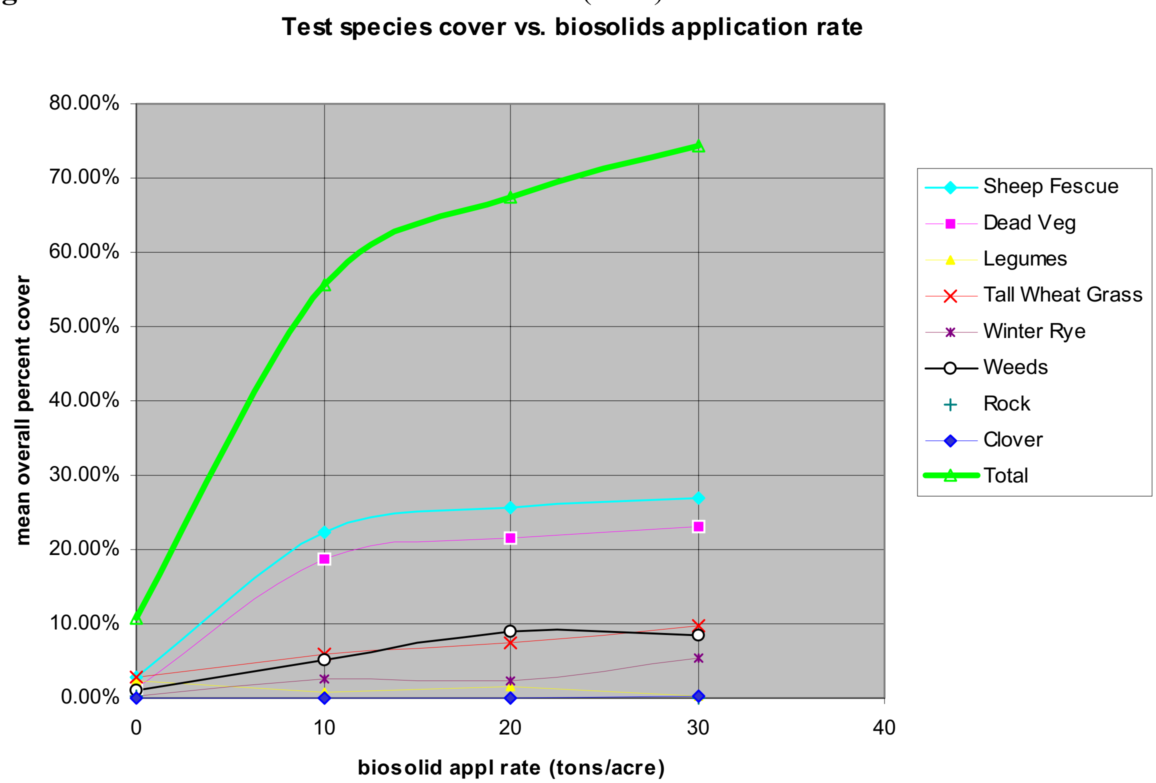

Figure 4. Change in biodiversity and inert matter between 1995 and 1996.