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Jasper County Final Report

Prepared by Sally Brown July, 2002

The University of Washington has worked with Mark Doolan, Region 7, Scott Fredericks, ERT, Mark Sprenger, ERT and the City of Springfield to establish large-scale demonstration sites to test the ability of biosolids + lime to restore a vegetative cover on mine chat in Jasper County, MO.

Mark Doolan identified three areas for large-scale application.

- Approximately 7-10 acres was amended with biosolids + lime at the Center Creek site. This portion of the project was initiated by MO DNR and the City of Springfield before the official demonstration project with UW had begun.
- Approximately 15 acres was set aside for the demonstration project at the New Repository.
- Approximately 3 acres at the Moehr property was identified for application of biosolids compost + lime.

The University entered into a sub contract with the City of Springfield to supply, apply and incorporate biosolids, biosolids compost and lime, and seed the identified areas. This sub contract ran until December 2000. The contract period was extended until March 2001 to allow for completion of the project. As part of a separate project, EPA set aside a portion of the New Repository for composting by the City of Springfield. This compost is to be used at a site in Webb City. This effort was intended as a separate agreement between the City of Springfield and Webb City. The final payment from the University of Washington to the City of Springfield has been made.

Research Results

1. **How does application of biosolids + lime affect groundwater quality?**

Initial proposed approach to this question was to install replicated small plots with lysimeters, with the objective of predicting nitrate contribution to groundwater aquifers from different application rates. After installation of the plots, Doolan requested the lysimeters be installed in large plots instead, and the small plots were subsequently demolished.

Lysimeters were then installed at the Moehr property and at the New Repository in the 50, 100 and 150 t/ac biosolids treatments, and the biosolids/wood mixture treatments. The lysimeters were installed after partial applications (some biosolids had been applied, but more was added after lysimeters were installed). Lysimeters were installed at 2' depth. Saturated soil was found above 2' depth for several of the lysimeters. In addition, a clay layer in the soil was found below the depth of the lysimeters, suggesting seasonal perched ground water. This indicates that there are at least two groundwater aquifers at this area of the New Repository. The shallower groundwater (probably seasonal) is presumably different from the primary groundwater supply for homes and streams in the area. Samples have been taken from the lysimeters over the course of the project. Nitrate concentrations in the water samples were measured. Results are presented below. In May, 2002 we attempted to take additional samples from the lysimeters but they had fouled over time. Samples were only collected from the Moehr property.

While the results indicate that nitrate leaching did occur from the biosolids, it is not possible to interpret the results and predict the impact of this leaching on groundwater quality, especially that used for drinking water. The choice of sites for sampling with the lysimeters have numerous problems that impact interpretation:

- The first is the aforementioned problem that they may have sampled a saturated zone (perched aquifer). This can accumulate nitrates, and the concentration may not be indicative of nitrates in the unsaturated zone (normally sampled with lysimeters).
- Unknown denitrifcation may have occurred as nitrates accumulated in the saturated zone.
- The hydraulics of the shallow aquifer are not known. Since the mass contribution of nitrates to a usable aquifer is a combination of the concentration and the mass flow of water, and since neither of these are known, this calculation cannot be made.

Additionally, Springfield made applications in lifts to these sites. The dynamics of nitrification, leaching and denitrification are tremendously affected by application technique. For instance, it has been found that nitrate production is far less with one heavy application than with a series of light applications, due to nitrification/denitrification interactions.

Table 1. Nitrate concentration in water collected from lysimeters that were installed in the New Repository and the Moehr property. Additional compost was added to the surface of the Moehr property just prior to the 12-00 sampling date. Biosolids and lime were applied to all sites at the New Repository until the 01-April sampling date.

	Water Nitrates	New Repository Oct-00	Dec-00	01-Apr	01-Jul
50 t/a	A1	78	1.3	52	No water
	A2	33.7	71.8	70	No water
150t/a	B1		221	246	No water
	B2		254	14	No water
	B3		165	307	No water
100 t/a	C1		143	220	No water
	C2	314	114	248	No water
Compost in place	D1	41.6		254	No water
Wood not yet applied	D2		241	164	No water

MOEHR	7 -00	10-00	12-00	4-01	7-01	5-02
M 1	7.63	8.61	137	410	No water	15.9
M 2	94.8	127	260	220	"	No water
M 3	3.19	28.6	260	260	"	42

2. **Is biosolids compost + lime a suitable restoration amendment for more populated areas?**

Approximately 3 acres at the Moehr property was regraded and a compost mixture was applied to the surface of the tailings. This surface application took place in two stages with the first being complete by June 2000 and the second completed by December 2000. There were no problems related to odor associated with the use of the compost. In addition, there was no observed movement of the compost from the application site into the pond. This indicates that the mixture is stable. Lysimeters were also installed at the site in June 2000 and samples have been collected throughout the year. Data is shown above

For the first year, as per the recommendation of John Meuhys (MO DNR), the area was seeded with Sudan grass. Plant samples were collected from both the amended and unamended areas. Sudan grass Zn, Cd, and Pb averaged 113, 0.86 and 1.26 mg kg^{-1} in the amended areas. Plants in the unamended areas had concentrations averaging 470 mg kg^{-1} Zn, 4.25 mg kg^{-1} Pb and 7.48 mg kg^{-1} Cd. The sudan was subsequently burnt off the site and it was reseeded with a native mixture. A photo of the site taken in May,2002 is included in the appendix. These results suggest that the compost was an effective amendment for more populated areas

3. Project Costs

Two potential sources of biosolids are being considered to develop cost estimates for a large-scale project. The City of Springfield has provided material for the current demonstration site. As of December, 2001 they had refitted their equipment and were able to relatively efficiently apply high rates of materials. In addition, this refitting enabled them to mix biosolids and lime prior to application and spread both with a single application. However, there have been some problems with working with the City. Malters has not been forthcoming with his billing or with modifying equipment and operations as had been discussed and agreed upon. Because of this, it is not clear if Doolan would continue to work with Springfield if the project were to go large-scale.

Based on the statement that was received by the UW in July, 2000, the City of Springfield charged $24,855 to haul 2762 cubic yards of cake to the site. In addition, The City charged $2,990 for site prep. Assuming that the cake was 18% solids, and that the material weighed 1 ton/cy – this comes to a total of approximately 500 dry tons of cake. This would bring the cost of land prep and cake application to $2785 per acre. The cost of lime would need to be added to this figure. We purchased lime from Calco in Carthage for the project. Lime delivered to the site was approximately $8 per ton. Using a 25 t/ac application rate, this would add $200 to the per acre price.

Based on the single bill received by UW from the City of Springfield in December, 2000, costs for the project are somewhat different. In this invoice, the City charged UW a total of $91,096 for treating 24 acres. This acreage figure takes into account higher application rates and credits those as additional acres. The $91,000 included $18,470 in rental costs. We requested copies of the receipts for the rented equipment. Malters has subsequently deleted these charges from the bill. It also includes $6,768 for limestone. This cost reflects the fact that Springfield contracted with a private company, rather than do application of limestone by themselves. With equipment modifications that were completed in December , 2000, it isn't necessary to have any additional contractors spread lime. If both the lime costs and rental costs are subtracted from the statement, the total cost for 24 acres comes to $65,858. This is equivalent to a per acre cost of $2750. One would need to add the cost of limestone delivered to the site for this to be accurate. That would add a total of $4800 to the project costs and would bring the total per acre cost of the amendment to $2950.

It should be noted that the final bill from the City of Springfield included an additional $28,000 in hauling costs. This corresponds to 720 dry tons of biosolids. Our calculations of the amount of area treated at the 50 t/a rate indicated that these costs referred to excess material that had potentially been brought and applied to the site. Some of this material would have been used to make compost. However, there is a high probability that biosolids were applied to at least a portion of the sites in excess of the recommended 50 t/a rate. This is understandable as Springfield didn't have appropriate application equipment until the end of the project. It may also represent an incorrect assessment of the number of acres treated.

4. Native plants

A large scale site at the New Repository was divided into subplots and seeded with a range of different natives and pasture grasses. A map of the seeding plan is included in the appendix. Seeding took place in April, 2001. A subsequent site visit in July, 2001 showed good germination and growth of orchard grass and tall fescue. The warm season grasses that had been tested did not germinate as well. Invasive weeds dominated the site. Excavated yard soils support a large population of these invasives. It would appear that, unless some attempt is made to either control the population of invasives on the yard soils, or to more intensively manage the invasives on the native grasses site, it will be difficult to restore a native cover to these soils. Photos of the site are attached along with Rick Mammen's evaluation.

In addition, a series of small scale plots have been installed at the new repository. Soil amendments here consisted of different ratios of biosolids and wood waste to look at the role of C:N ratio to native plant populations. Results from that study are presented later in the document It may also be possible to encourage native plant growth by having several croppings of a high yielding grass crop immediately after amendment addition. This rapidly growing can take up some of the excess nitrogen existing on the site following application. Incorporation of the green mulch into the soil will add to soil organic matter.

Plant and soil data : Native grasses, soil amendments

All of the areas that had been initially identified for biosolids + limestone application at 50 t/a biosolids + 25 t/a limestone rates have been treated with the designated mixture. Material has been incorporated and seeded. Treated areas were seeded with both native warm season grasses and legumes and pasture grasses as recommended by Rick Mammen, State extension service. Seed was purchased and applied by UW (City of Springfield prepped the fields for seeding – dragging a chainlink fence over areas before and after seeding). Growth from the first and second seasons indicates that this mixture is sufficient to restore a plant cover on the identified sites. The site (as of 6/2002) has a complete and dense vegetative cover

Native grasses

Corresponding plant and soil samples were collected from the New Repository and Center Creek sites in July 2001. Additional plant samples were collected from the New Repository in May 2002. Plants were analyzed for total elemental concentrations. Soil samples were analyzed for total metals, pH and plant available metals as extracted by 0.01 M $CaNO_3$.

The pH in the native grass plots did not reach the desired value of >7 in 2001. This may be due to the complications in getting lime applied to the site by outside contractors. Despite this, plant metal concentrations were generally below levels of concern in the 2001 sampling. All values for orchard grass in the 2002 spring sampling were either below detection (Cd and Pb) or within normal ranges (Zn). However, this was not the case for Zn uptake by big blue stem and side oats gamma at the New Repository in 2001. Also in 2001, plant Zn concentrations for big blue grown at Center Creek with higher total soil Zn is within acceptable levels. In general, the Cd and Pb content of the grasses for both sampling periods are low enough to suggest that any danger to herbivores consuming these grasses is minimal. In certain cases, the Zn content of grasses was high enough in 2001to suggest some grasses may have experienced some metal associated stress. Levels were low enough in the 2002 sampling that no abnormal plant response would be expected. The sampling indicates that total metal concentrations vary widely across a relatively small area. The $Ca(NO_3)_2$ metal value is a dilute salt extractable metal. In many cases, this extract is seen as a measure of the bioavailable fraction of the total metal.

Additional plant samples were collected in May, 2002 (table 4). These consisted of different grasses including orchard grass. Elemental concentrations of these tissues suggest a decrease in metal availability over time. These results are typical of metal content of grasses grown on uncontaminated soil and represent no potential for damage to herbivores grazing on the vegetation.

The observed decrease in plant metal concentrations from 2001 – 2002 is probably the result of the slowed decomposition of the biosolids. Similar decreases in plant tissue metal concentration were observed at the upland replicated field plots in Bunker Hill, ID. At the Bunker Hill site, third year plant tissue values were similar to those found during the second season. This suggests that elevated metal concentrations as a result of biosolids decomposition are a temporary phenomena.

Table 1. Plant Cd concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH		**Plant Cd**		**CaNO3Cd**	
Warm season	6.20±	0.28	0.45±	0.18	0.03±	0.01
Orchard Grass	5.93±	0.12	1.15±	0.37	0.05±	0.02
Big Bluestem	6.30±	0.27	0.16±	0.01	0.78±	0.18
Little Bluestem	6.57±	0.18	0.14±	0.05	0.02±	0.01
Big Bluestem Center Creek	6.41±	0.06	1.72±	0.68	0.04±	0.01
Turkey foot	5.97±	0.06	0.22±	0.04	0.03±	0.01
Indian Grass	6.00±	0.19	0.11±	0.02	0.52±	0.39
Sideoats Gama	6.07±	0.27	0.23±	0.02	0.06±	0.01
Fescue	6.12±	0.11	1.64±	1.07	0.05±	0.01
Moesby Mix	6.04±	0.15	0.15±	0.01	0.03±	0.00

Table 2. Plant and soil Pb concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH		Plant Pb		Pb total		$CaNO_3$ Pb	
Warm season	6.20±	0.28	10.93±	7.31	253±	25	0.16±	0.17
Orchard Grass	5.93±	0.12	5.44±	1.88	519±	207	0.51±	0.42
Big Bluestem	6.30±	0.27	12.96±	7.72	620±	153	0.10±	0.04
Little Bluestem	6.57±	0.18	6.85±	1.89	259±	30	-0.08±	0.01
Big Bluestem	6.41±	0.06	9.56±	4.19	766±	276	0.70±	0.23
Turkey ft	5.97±	0.06	10.80±	5.03	247±	46	0.14±	0.02
Indian Grass	6.00±	0.19	11.01±	8.36	412±	68	0.10±	0.06
Sideoats Gama	6.07±	0.27	6.38±	0.88	302±	41	0.10±	0.05
Fescue	6.12±	0.11	4.70±	0.29	711±	70	1.84±	0.80
Moesby Mix	6.04±	0.15	5.17±	1.65	292±	58	0.08±	0.04

Table 3. Plant and soil Zn concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH		Plant Zn		Zn total	$Ca(NO_3)_2$ Zn	
Warm season	6.2±	0.3	91±	28	725 ± 197	1.0±	0.4
Orchard Grass	5.93±	0.1	197±	53	354 ± 73	2.0±	1.0
Big Bluestem	6.3±	0.3	247±	81	1565 ± 132	100.2±	28.4
Little Bluestem	6.57±	0.2	217±	60	574 ± 107	1.1±	0.5
Big Bluestem (Center Creek)	6.41±	0.1	119±	27	4440 ± 1920	3.6±	1.5
Turkey ft	5.97±	0.1	153±	17	458 ± 123	1.2±	0.4
Indian Grass	6±	0.2	213±	34	2345 ± 1026	78.3±	63.5
Sideoats Gama	6.07±	0.3	282±	43	752 ± 67	3.0±	0.6
Fescue	6.12±	0.1	172±	76	922 ± 172	3.1±	1.2
Moesby Mix	6.04±	0.2	88±	15	489 ± 125	1.4±	0.5

Table 4. Metal concentration of orchard grass samples collected from the New Repository in May,2002 from an area that had been amended with 50 t/a biosolids + 25 t/a limestone. BD stands for below detection limit.

	Plant Cd	Plant Pb	Plant Zn
Sample 1	BD	BD	50
Sample 2	BD	BD	70
Sample 3	BD	BD	73
Sample 4	BD	BD	96

Soil Amendments

To test the potential for different biosolids + lime soil amendments to provide a superior plant cover, single large-scale plots (1 acre) were established at the New Repository. Treatments included:

- 50 t/ac biosolids + 25 t/ac lime
- 100 t/ac biosolids + 50 t/ac lime
- 150 t/ac biosolids + 75 t/ac lime
- 50 t/ac biosolids + 100 t/ac wood + 25 t/ac lime
- 50 t/ac biosolids + 100 t/ac phosphogypsum + 25 t/ac lime

Amendment application was completed in June 2001, approximately 14 months after applications began. (Note: A large portion of the area treated with 50 t/ac has been set aside for highway construction, and may not be available for long-term monitoring.)

As part of the agreement with UW, the City of Springfield was supposed to seed these areas with Sudan grass after amendment application. The invasive nature and persistence of the Sudan at the Moehr property was sufficient cause to change these plans. Instead, UW seeded the plots with oats in July, 2001. The oats had limited germination as they were seeded during a very hot and dry period of the summer. Volunteer species took over the site in 2002. These consisted primarily of ragweed with some grasses.

Soil Treatments

Plant tissue samples were collected in both the fall of 2001 and spring of 2002. In general plant tissue concentrations decreased over the two sampling periods. In the 2002 sampling, plant Cd concentrations were below detection limits for all samples from the biosolids @150 t/a treatment and were close to detection limits for all other treatments. The observed decrease in metal content is likely the result of the stabilization of the amendment. Rapid decomposition of biosolids will occur in the period after application. For both sampling periods, there did not seem to be an obviously superior treatment amoung the soil amendments tested. Plant metal concentrations appear to be lowest in the compost and biosolids @150 plots, however, concentrations were generally acceptable across all treatments. Individual values as well as the means for each treatment are shown below for 2001. Means and standard deviation are shown for 2002. Total soil and plant P are also shown. Addition of phosphogypsum did not increase total soil or plant P for both sampling periods. Pictures of the plots from the 5/2002 sampling date are included in the appendix. While there were differences in total plant cover, plants in all treatments were very healthy and elemental analysis suggests that all treatments are capable of supporting a dense cover that poses no threat to herbivores that ingest plant material grown on the restored chat.

Table 1. Soil pH, total and extractable Cd and plant Cd for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Cd	CaNO3 Cd	Plant Cd
Compost	6.45	4.0	0.04	0.63
Compost	6.45	10.0	0.03	0.65
Compost			0.03	0.56
Compost	6.51	4.3	0.05	0.55
	6.47	**6.08**	**0.04**	**0.60**
Phospho	6.11	12.2	0.06	1.19
Phospho	6.21	7.6	0.06	0.75
Phospho	6.11	20.0	0.07	0.69
Phospho	6.34	19.6	0.05	0.86
	6.19	**14.86**	**0.06**	**0.87**
BS @ 50	5.75	6.6	0.05	0.36
BS @ 50	5.52	4.3	0.06	0.41
BS @ 50	5.37	6.0	0.06	0.44
BS @ 50	5.57	7.9	0.04	0.63
	5.55	**6.19**	**0.05**	**0.46**
BS @ 150	5.73	7.5	0.04	0.56
BS @ 150	6.31	7.1	0.04	0.62
BS @ 150	6.21	7.0	0.03	0.50
BS @ 150	6.15	5.7	0.03	0.46
	6.1	**6.83**	**0.04**	**0.53**
BS @ 100	6.18	3.8	0.02	0.55
BS @ 100	6.11	15.6	0.01	0.36
BS @ 100	6.42	4.6	0.00	0.54
BS @ 100	6.17	10.2	0.01	0.72
	6.22	**8.53**	**0.01**	**0.54**

Table 2. Soil pH, total and extractable Pb and plant Pb for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Pb	CaNO3 Pb	Plant Pb
Compost	6.45	237.4	0.31	6.51
Compost	6.45	688.2	0.43	4.94
Compost			0.25	2.04
Compost	6.51	428.5	0.22	3.08
	6.47	**451**	**0.3**	**4.1**
Phospho	6.11	788.3	0.92	4.34
Phospho	6.21	613.9	0.64	3.32
Phospho	6.11	305.3	0.31	5.84
Phospho	6.34	298.7	0.36	5.28
	6.19	**502**	**0.6**	**4.7**
BS @ 50	5.75	614.3		
BS @ 50	5.52	755.6	1.27	6.09
BS @ 50	5.37	506.9	1.90	3.86
BS @ 50	5.57	224.0	0.30	2.20
	5.55	**525**	**1.2**	**4.0**
BS @ 150	5.73	375.8	0.38	1.58
BS @ 150	6.31	595.9	0.39	2.17
BS @ 150	6.21	530.3	0.41	4.02
BS @ 150	6.15	358.4	0.35	2.40
	6.1	**465**	**0.4**	**2.5**
BS @ 100	6.18	478.2	0.83	2.96
BS @ 100	6.11	510.3	0.61	4.50
BS @ 100	6.42	729.9	1.20	8.88
BS @ 100	6.17	1257.0	1.73	11.27
	6.22	**744**	**1.1**	**6.9**

Table 3. Soil pH, total and extractable Zn and plant Zn for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Zn	CaNO3 Zn	Plant Zn
Compost	6.45	404.8	0.21	94.5
Compost	6.45	1210.7	0.33	85.8
Compost			1.52	97.2
Compost	6.51	467.6	0.34	83.2
	6.47	**694**	**0.6**	**90**
Phospho	6.11	677.1	1.97	166.1
Phospho	6.21	472.0	1.32	107.2
Phospho	6.11	1957.0	1.50	100.3
Phospho	6.34	1938.2	0.97	112.6
	6.19	**1261**	**1.44**	**122**
BS @ 50	5.75	611.9		
BS @ 50	5.52	959.6	0.85	138.4
BS @ 50	5.37	639.6	1.39	144.3
BS @ 50	5.57	1027.0	1.69	139.9
	5.55	**809**	**1.31**	**141**
BS @ 150	5.73	1213.6	1.48	88.1
BS @ 150	6.31	1094.0	0.81	90.5
BS @ 150	6.21	713.7	0.62	120.9
BS @ 150	6.15	662.2	0.53	98.7
	6.1	**921**	**0.86**	**100**
BS @ 100	6.18	658.7	0.60	99.0
BS @ 100	6.11	518.0	0.41	103.1
BS @ 100	6.42	1986.0	0.52	69.8
BS @ 100	6.17	658.2	0.49	82.0
	6.22	**955**	**0.50**	**88**

Table 4. Total soil P and plant P for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	Total P		Plant P	
Compost		7575.8		7136
Compost		10117.5		5337
Compost				7862
Compost		9500.6		6460
	9065		**6699**	
Phospho		6621.9		7396
Phospho		5759.9		6853
Phospho		5862.0		5522
Phospho		5922.2		7574
	6041		**6836**	
BS @ 50		7234.6		
BS @ 50		7534.9		5188
BS @ 50		7331.9		4717
BS @ 50		21841.4		10223
	10986		**6709**	
BS @ 150		16085.9		8565
BS @ 150		9291.1		8146
BS @ 150		9812.4		10799
BS @ 150		10968.6		6832
	11540		**8586**	
BS @ 100		9577.8		6519
BS @ 100		8410.0		7610
BS @ 100		6023.5		4393
BS @ 100		5352.7		7000
	7341		**6381**	

Table 5. Foliar tissue concentration of grass samples collected from the large -scale treatment plots in May, 2002. Means plus standard deviation are presented (n=3)

Treatment		Plant Cd	Plant Zn	Plant Pb	Plant P
Biosolids	50	0.11±0.19	63 ± 9.8	0.47 ± 0.34	3725 ± 350
	100	0.26 ± 0.37	66 ± 14	4.8 ± 5.08	4334 ± 1030
	150	0	51 ± 26	0.2 ± 0.18	4260 ± 605
Compost		0.05 ± 0.08	30 ± 3	0.57 ± 0.55	4225 ± 275
PG +Biosolids		0.17 ± 0.12	79 ± 43	17 ± 0.59	4334 ± 180

Native plant C:N ratio

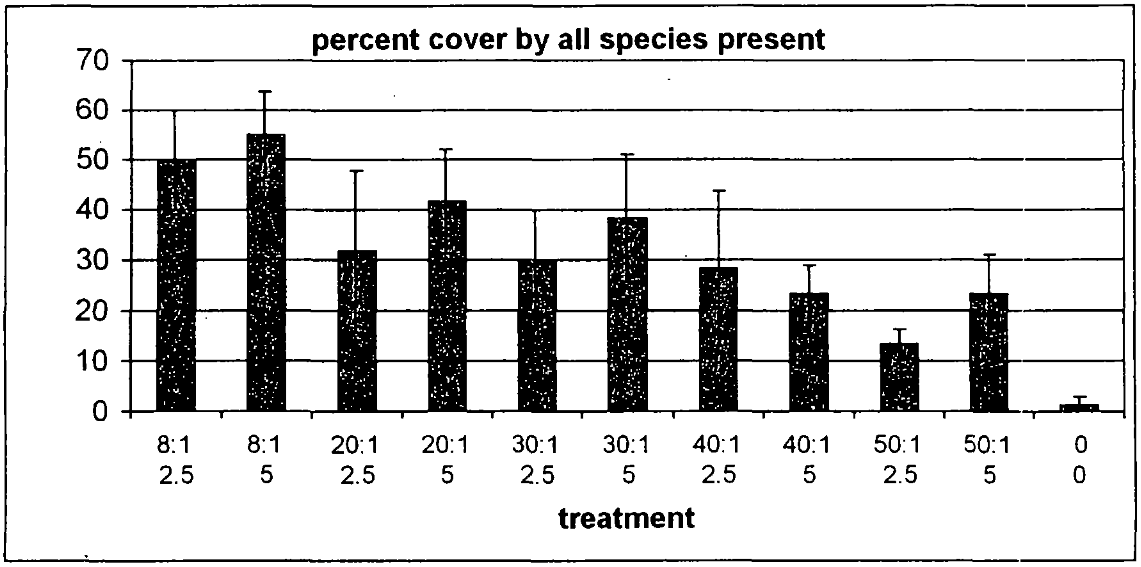
A series of small scale plots have been installed at the New Repository. Soil amendments here consisted of different ratios of biosolids and wood waste to look at the role of C:N ratio to native plant populations. Each plot was seeded with a grass and a legume species. These plots are useful as they should indicate if altering the C:N ratio of the amendment encourages natives. In addition, they will also indicate if increasing organic matter by increasing the application rate of amendments is useful for improving plant cover. A photo of the plot area is included in the appendix.

Initial data from the native plant C:N study show trends rather than distinct results. Percent cover was greatest in the plots that contained primarily biosolids (see figure 1). This was true for both the October, 2001 and May, 2002 sampling events. The lower C:N ratio of the organic matter may provide a more fertile growing environment. Within the same C:N ratio, higher rates of organic matter addition (5% vs 2.5% total organic matter) also showed better plant cover. This suggests that low C:N ratios with high rates of organic matter addition (or high application rates of amendments) may provide the best initial cover for the treated areas.

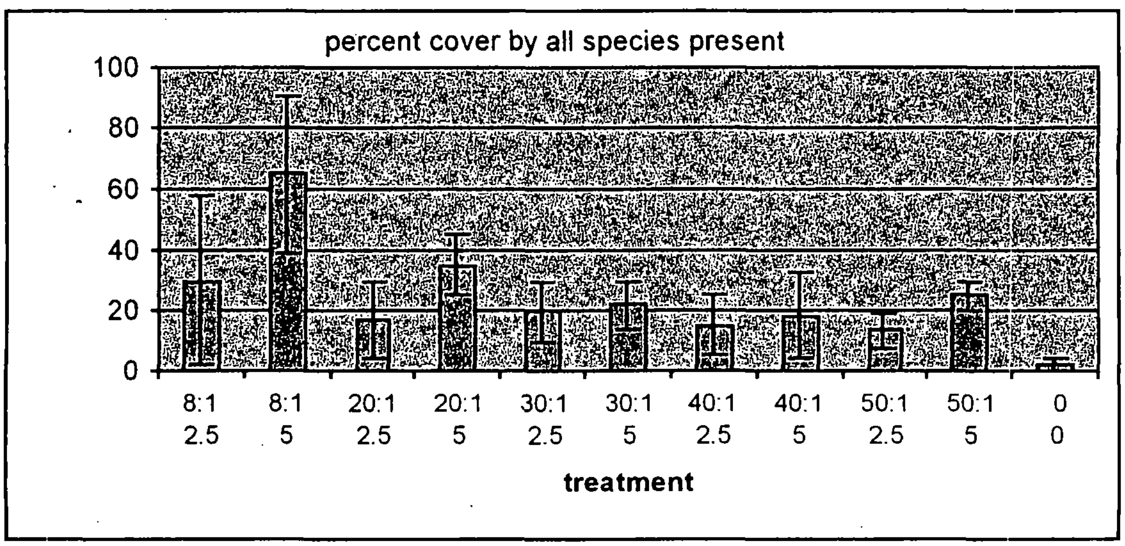
It was thought that increasing the C:N ration would facilitate restoring a native cover to the treated areas. Natives are not adapted to growing in heavily fertilized soils. By increasing the C:N ratio of the amendment, it was thought that the natives would be more competitive against the invasive species. It was also thought that the legume species would be more competitive at the higher C:N ratio treatments (see figure 2). This does not seem to be the case. Initial results from the plots don't show a clear pattern. The data suggests that the number of legume species is increased when organic matter is added to the soil at the higher rate (5%) of addition. The C:N ratio does not seem to have a clear effect on the population of grasses vs legumes.

It may also be possible to encourage native plant growth by having several croppings of a high yielding grass crop immediately after amendment addition. This rapidly growing can take up some of the excess nitrogen existing on the site following application. Incorporation of the green mulch into the soil will add to soil organic matter.

Figure 1. Percent cover by all species present in October, 2001 (a) and May, 2002 (b)

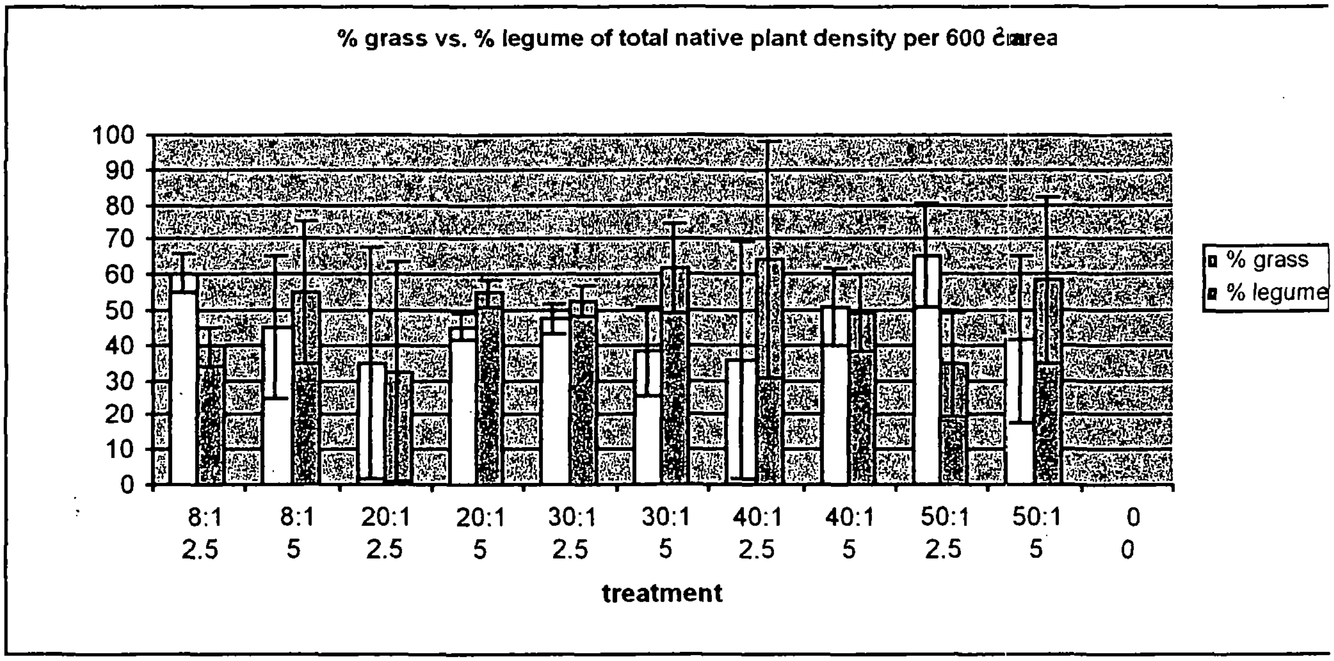


(a)

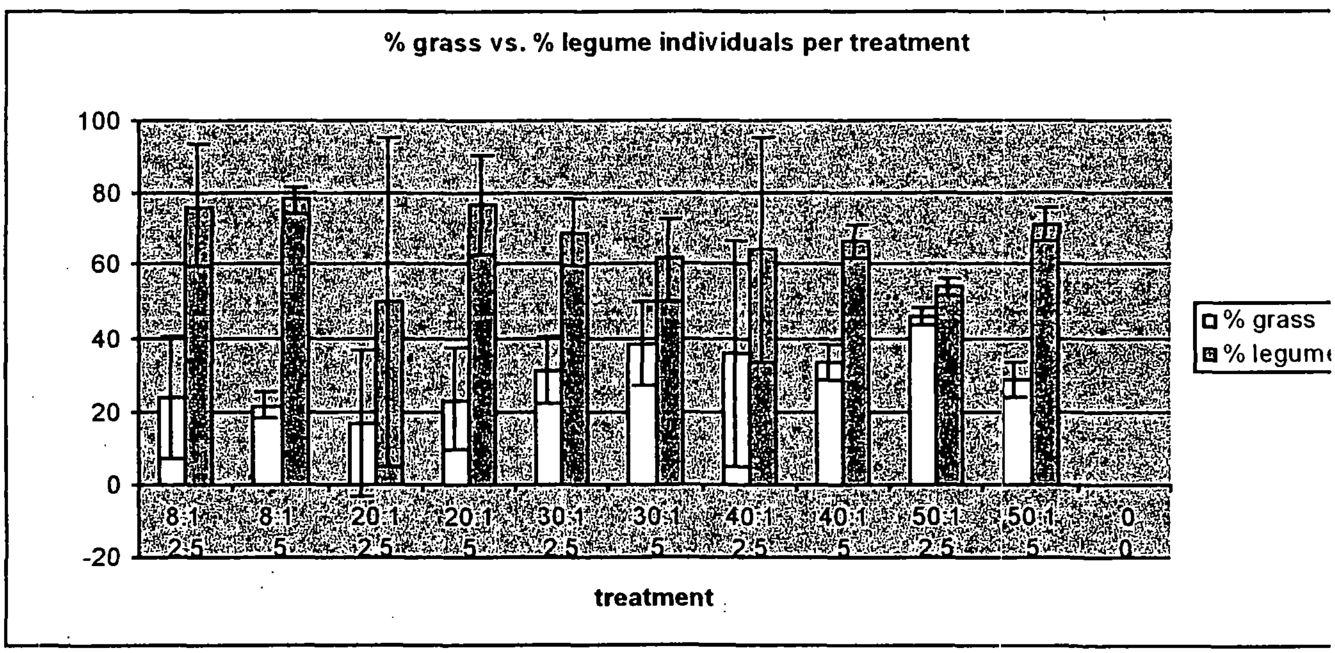


(b)

Figure 2. Relative numbers of grasses and legume in small scale plots for October, 2001 (a) and May, 2002 (b) sampling periods



(a)



(b)

Would inclusion of phosphogypsum in the amendment mixture improve the characteristics of the mix?

Phosphogypsum has been included in one of the large-scale plots at the New Repository. Results from that site are presented above. In addition to that, a greenhouse study was conducted at UW to test different rate combinations of phosphogypsum + biosolids. Results for plant growth and metal uptake and changes in soil physical properties are presented below.

All treatments for this study, except the control, included limestone addition. In addition to changes in soil physical properties, plant growth and metal content were measured. Three cuttings of rye grass were taken before soils were analyzed for changes in fertility and physical properties. This was done to allow the amendments to stabilize and to permit the development of any soil aggregates.

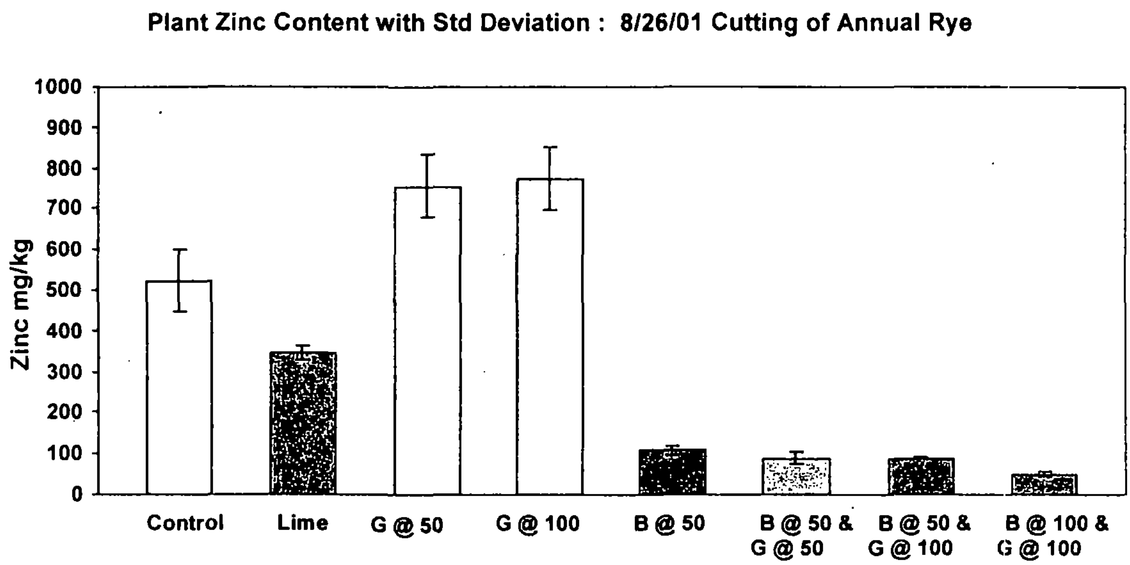
Table 1. Treatments used in the greenhouse study to examine changes in soil physical properties as a result of amendment.

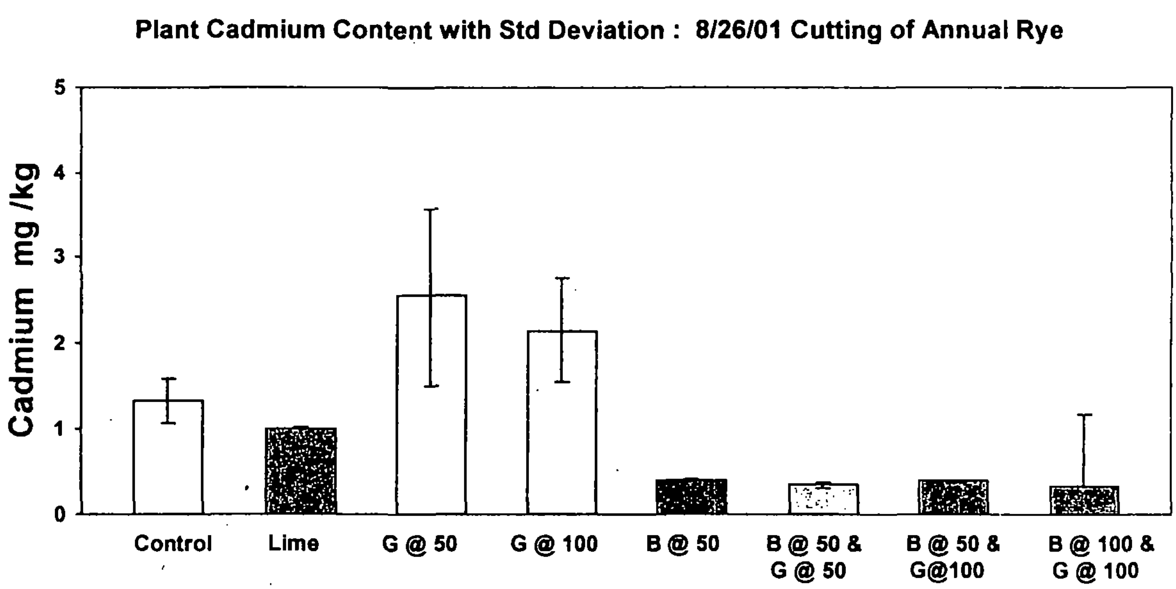
	Biosolids	P-Gypsum	Lime	Tailings
		Tons/acre		
Control				1000
Lime			25	1000
Biosolids	50		25	1000
P-gypsum		50	25	1000
P-gypsum		100	25	1000
Bio+ P-gypsum	50	50	25	1000
Bio+ P-gypsum	50	100	25	1000
Bio+ P-gypsum	100	100	25	1000

Plant Response

Plant growth as well as plant tissue metal concentrations were best in the treatments that included biosolids. Combining biosolids with PG didn't improve growth or reduce metal uptake (figures 1 and 2). Combining these amendments also did not have any apparent negative effects. Phosphogypsum, when added to soil in combination with biosolids does not appear to have any detrimental effects on plant growth or metal uptake. Amending the soil with PG alone appears to increase plant Zn and Cd uptake. However, in all treatments that included biosolids, plant Zn was well below any toxic threshold and was within normal ranges. Plant Cd and Pb were also very low and suggest that consumption of the grass would not pose any threat to animals. Yield increased with increasing application rates of both amendments. Yield for PG alone at either 50 or 100 t/a was much lower than any of the treatments that included biosolids. The highest yield was observed in the 100 t/a biosolids + 100 t/a PG treatment.

Figure 1. Rye grass Zn (a), Cd (b) and Pb(c) concentrations for plants grown in the greenhouse on chat collected from the New Repository. These values are from the 2nd cutting of the rye grass. Plant metal content was similar across all harvests.





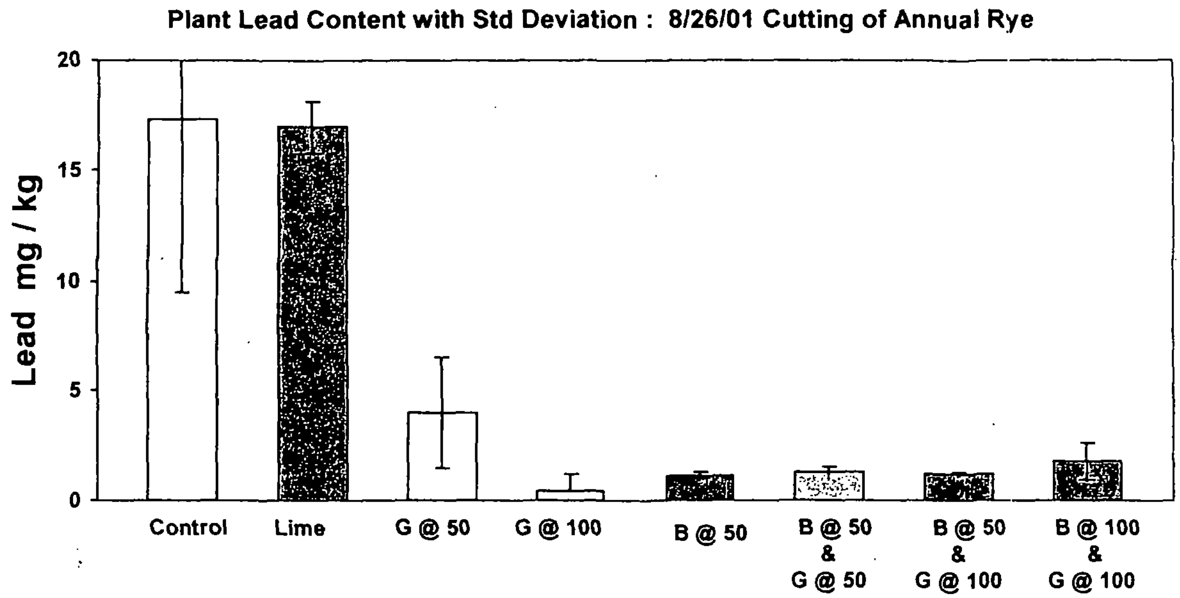
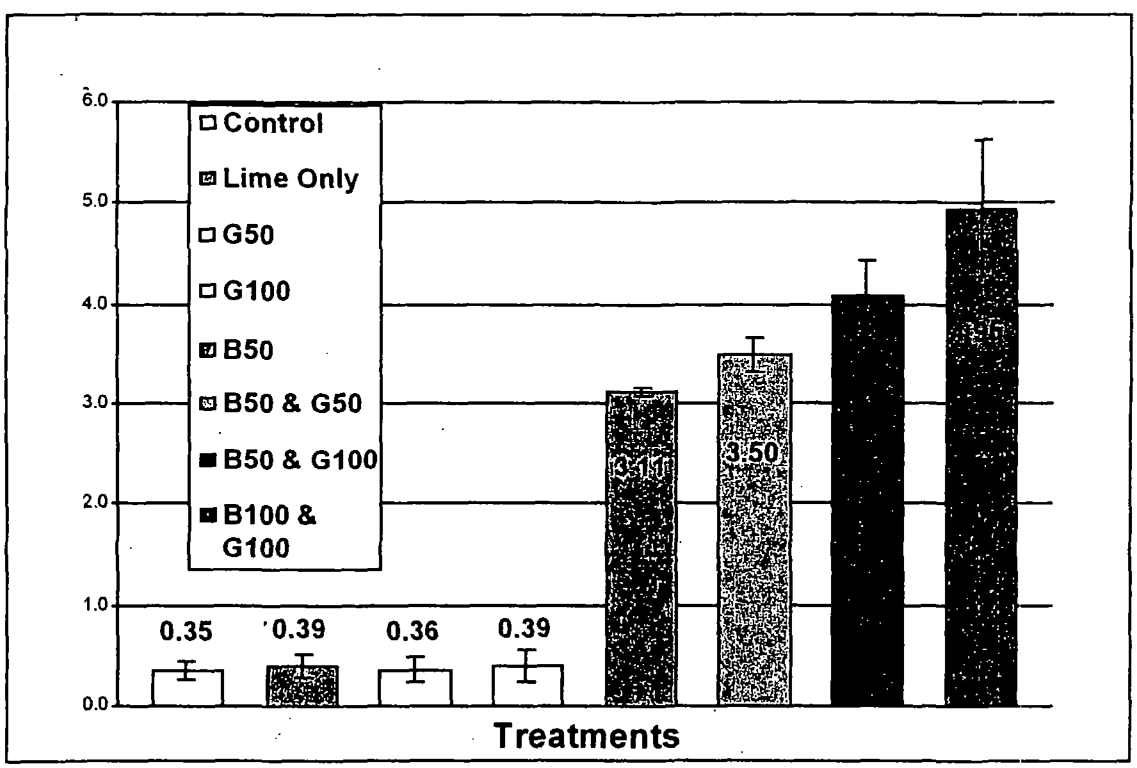


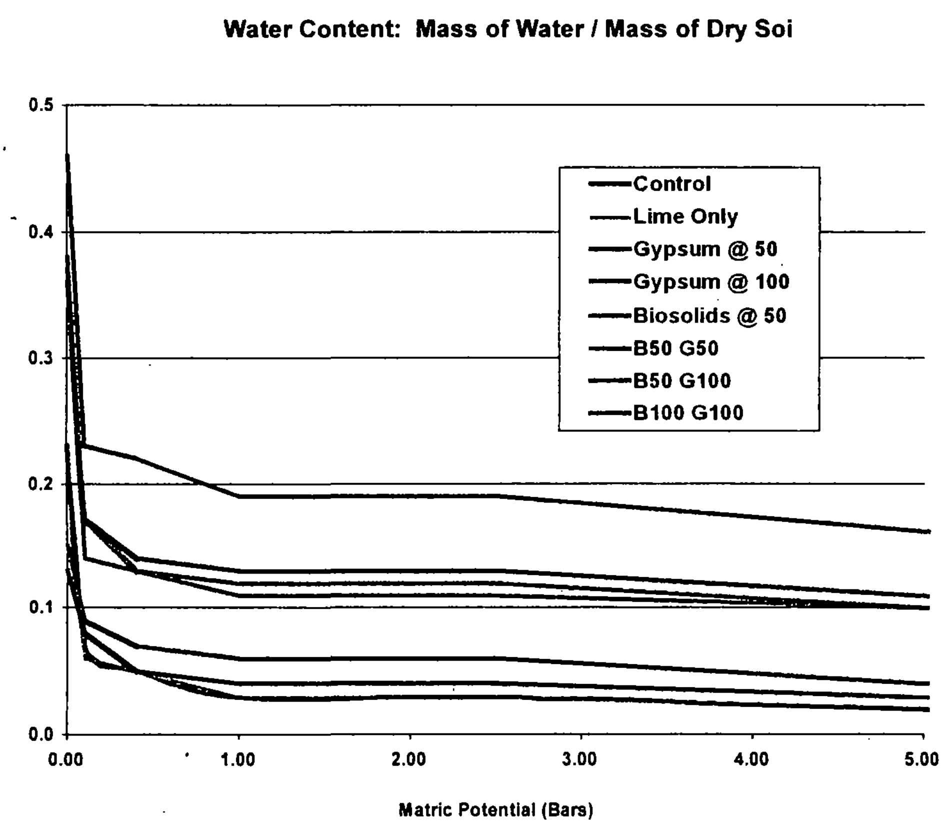
Figure 2. Plant biomass for rye grass. Values presented are the mean + standard deviation for sum of the yield from harvests 1 and 2.



Soil Physical Properties

For this study, the soil physical properties measured included soil water holding capacity (a measure of the soils ability to supply adequate moisture for plant growth), cation exchange capacity (soil fertility) and particle size (figures 3, 4 and 5). For the water holding capacity, water content was measured at a range of different moisture potentials. High total water content indicates increased water holding capacity. Increased water holding capacity and increased cation exchange capacity appeared to be a function of increased biosolids application rate. While there may be a small increase in water holding capacity due to increased rates of PG addition, this is minor in comparison to the increases observed as a result of biosolids addition. Particle size was the only variable that was changed by PG addition. Phosphogypsum increased the < 2 mm size fraction of the soil. This increase may, over time result in better soil aggregation and also increased water holding capacity and infiltration. However, these changes were not observed in the duration of the greenhouse study.

Figure 3. Water holding capacity of the soils from the greenhouse study.



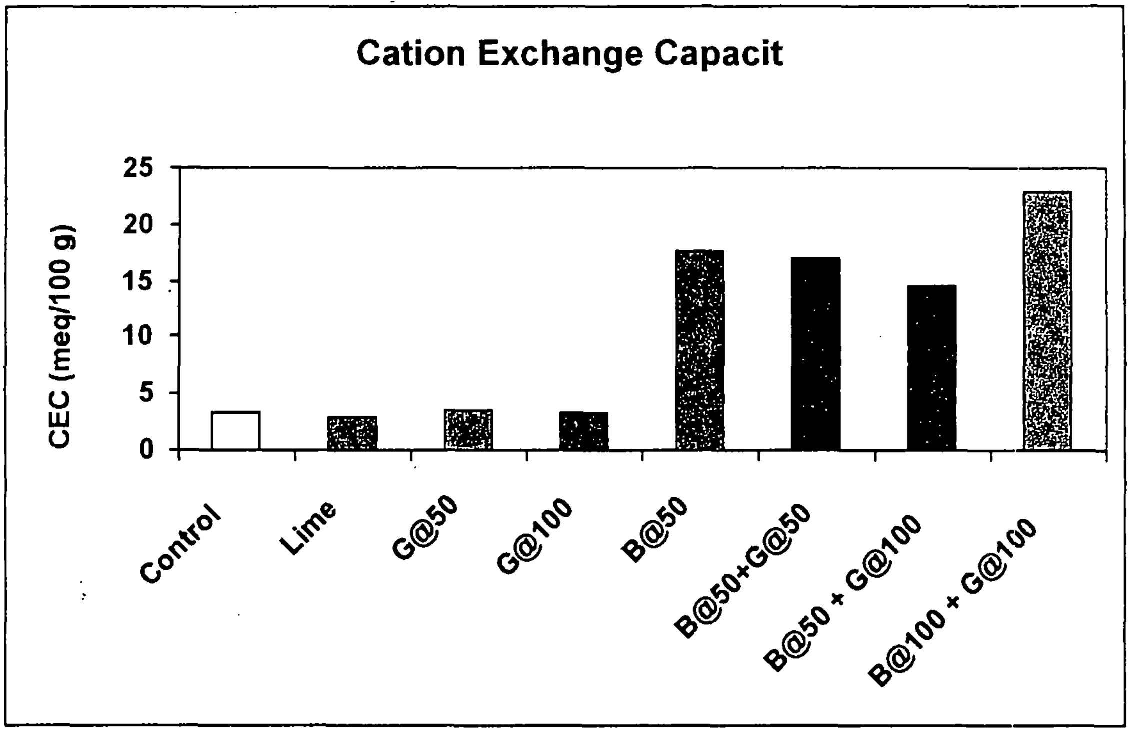
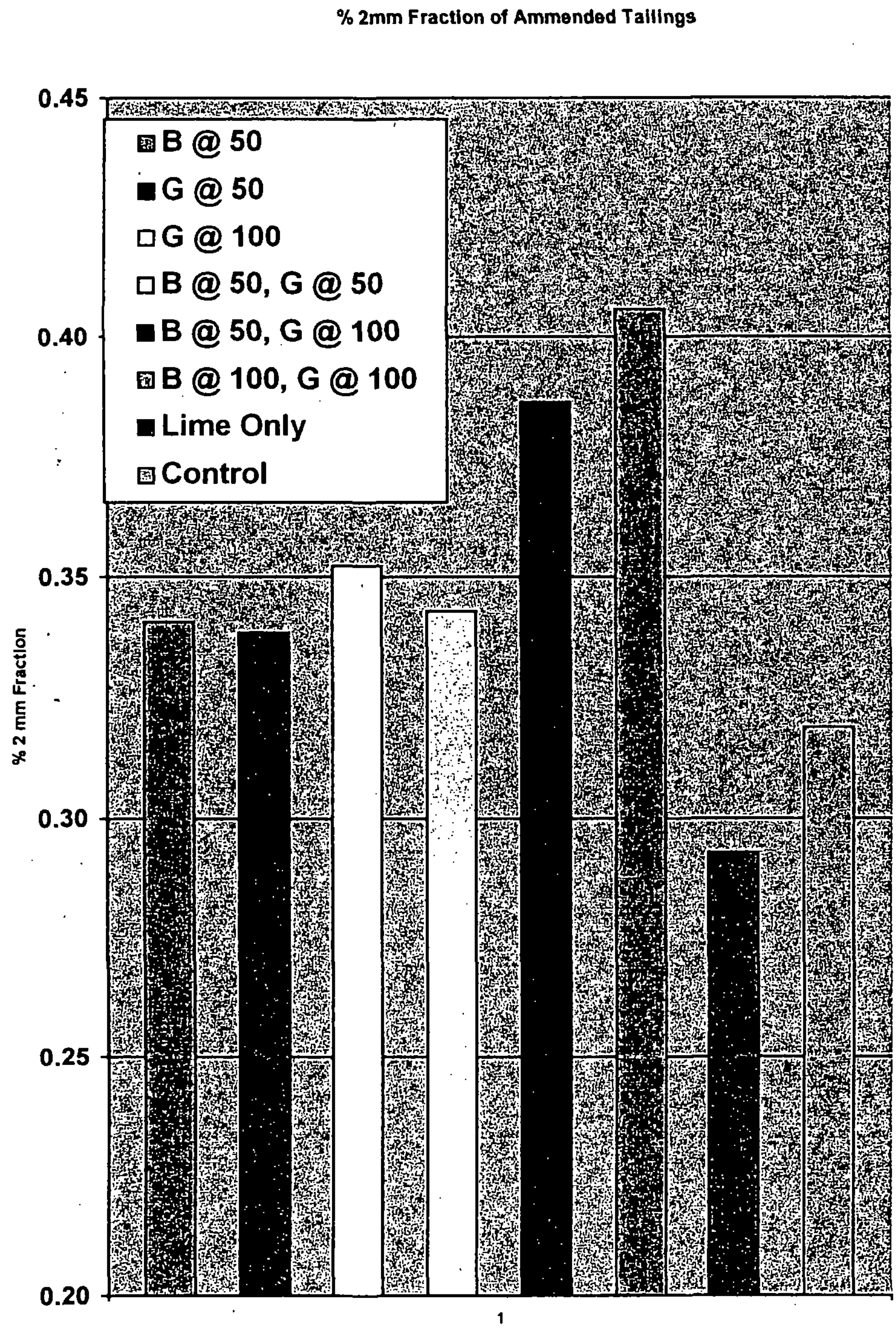


Figure 4. Cation exchange capacity of the soils from the greenhouse study.

Figure 5. Percent of the total soil that falls below the <2 mm particle size class. This size class is generally used to define the soil fraction of a sample.

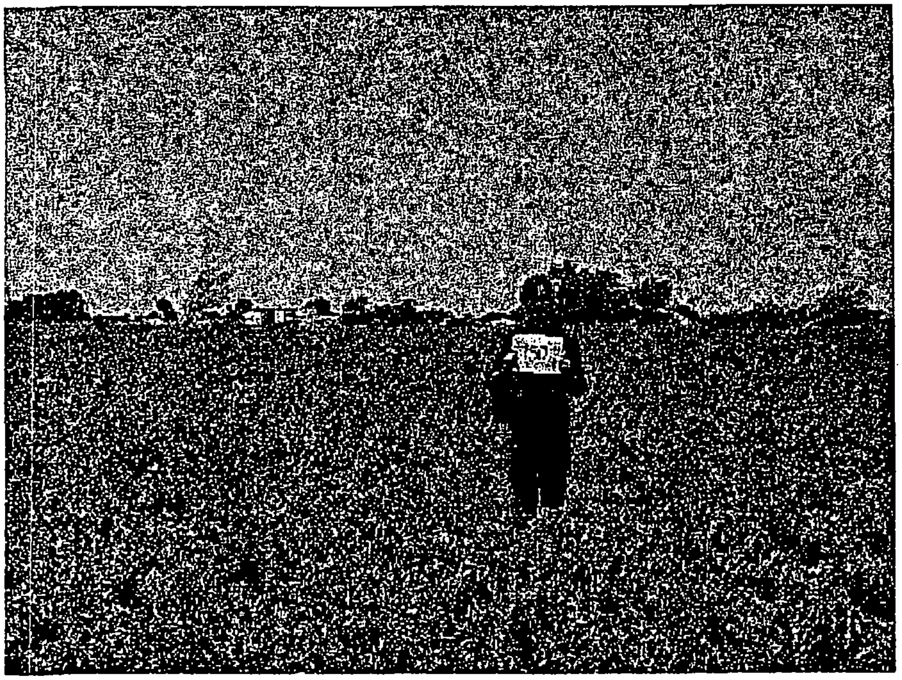


Appendix

Photos of the large scale plots testing different application rates of biosolids as well as different amendment combinations (a) biosolids @50, (b) biosolids @100, (c) biosolids @150, (d) compost in place, and (e) phosphogypsum. Plants for each treatment consisted of volunteer species and were primarily ragweed in all plots except the biosolids @ 50 treatment.

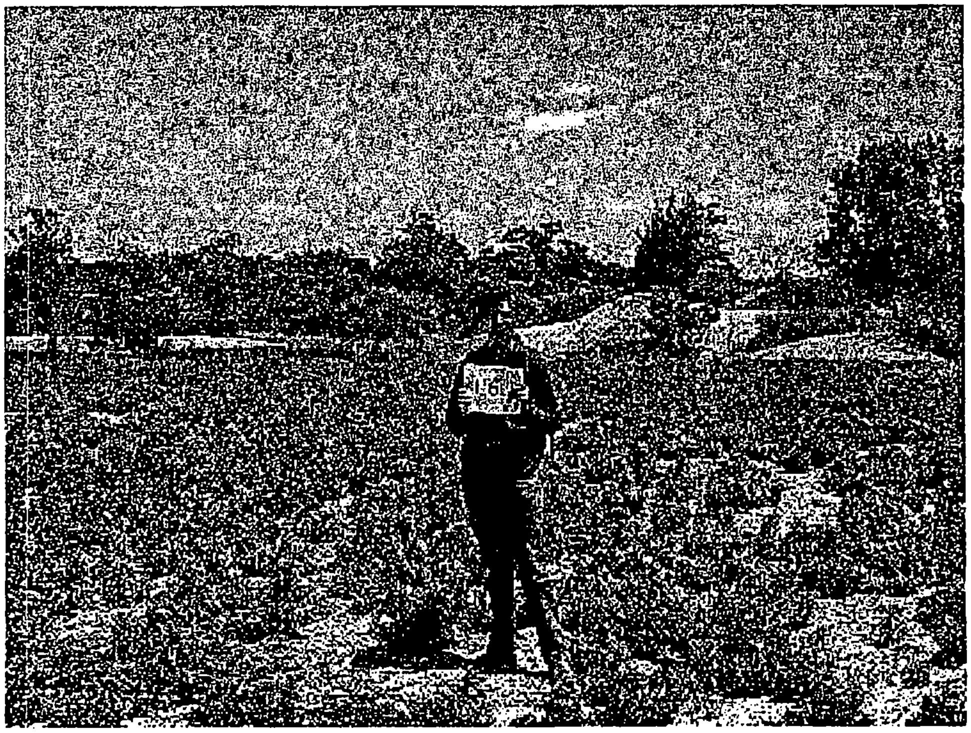
a

b

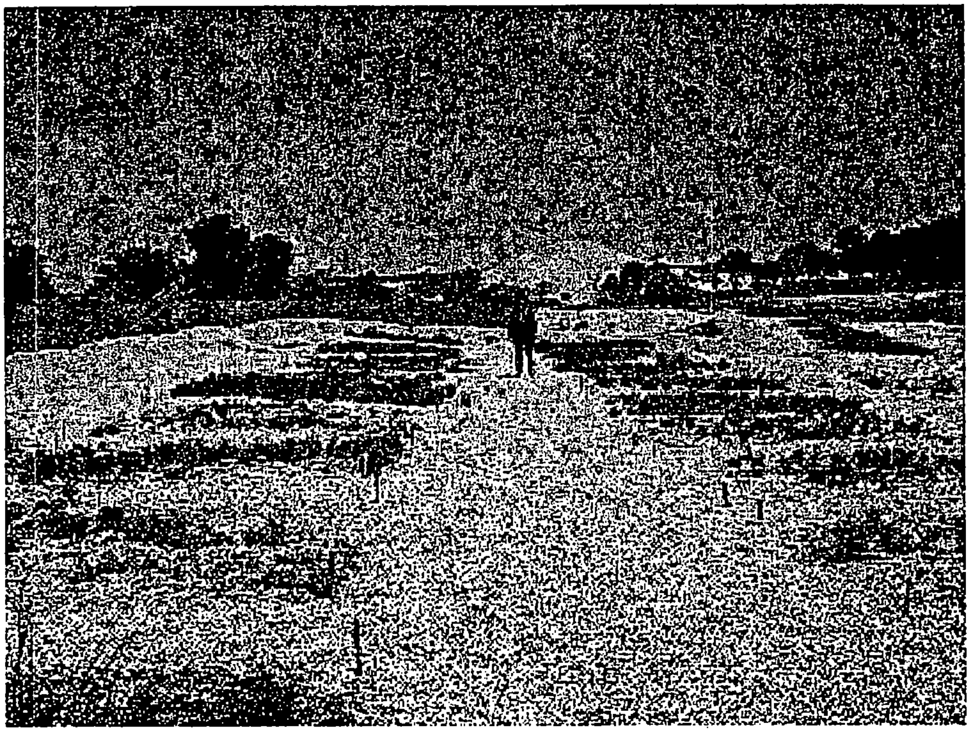


c

d



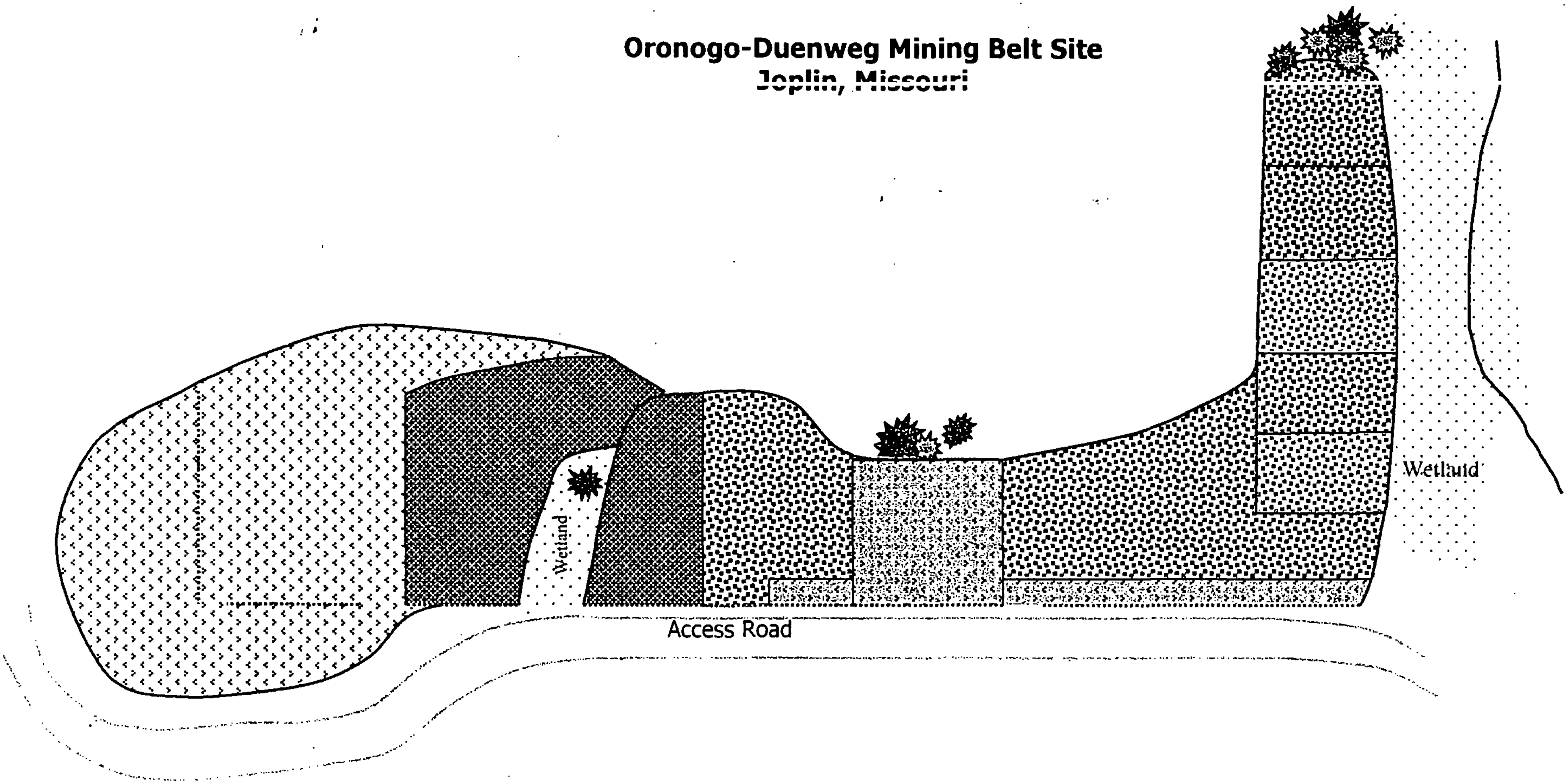
C:N ratio small plots, to test the importance of organic matter addition rate as well as the Carbon:Nitrogen ratio of the amendment for establishment of a native plant cover. Photo was taken in May, 2002



Moehr property in May, 2002. Sudan grass had been burnt in 2001. Vegetation shows a combination of natives and invasive species

EPA Demonstration Plots

Oronogo-Duenweg Mining Belt Site
Joplin, Missouri



KEY

Tall Fescue	*Lolium arundinaceum* (Schreb.) S.J. Darbyshire
Orchard Grass	*Dactylis glomerata* L.

Missouri DNR mix

Sand dropseed	*Sporobolus cryptandrus* (Torr.)
Indiangrass	*Sorghastrum nutans* (L.) Nash
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Sand lovegrass	*Eragrostis trichodes* (Nutt.) Wood
Sand bluestem	*Andropogon hallii* Hack.
Switchgrass	*Panicum virgatum* L.
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash

Warm season grasses mix

<u>*single species plots*</u>

Big bluestem	*Andropogon gerardii* Vitman
Switchgrass	*Panicum virgatum* L.
Indian grass	*Sorghastrum nutans* (L.) Nash
Sideoats grama	*Bouteloua curtipendula* (Michx.)
Little bluestem	*Schizachyrium scoparium* (Michx.)

MAP NOT TO SCALE

Jasper County Biosolids Demonstration – Data to date

Field samples were collected in July, 2001 and in October, 2001 from the amended areas of the New Repository as well as from the Center Creek demonstration area in July. For each sampling event, soil and plant tissue samples were collected from the same area so that data would be available to match soil characteristics with plant uptake.

Native grasses

The first sampling effort concentrated on collecting plants from the large area that had been seeded in the spring of 2001, using a range of seed mixtures. In general, single species samples were collected. This area had been treated with biosolids applied at 50 t/a and limestone at 10-25 t/a. The Center Creek site had received a heavier application rate of biosolids and lime. The collection was done by Barbara Christensen and Pam DeVolder. They collected 4 sub-samples of each species. For this collection, total soil metals were determined using an XRF with Mark Doolan's assistance. Additional soil parameters were measured in the laboratory at the University of Washington.

Soil amendments

For the October sampling event, plant and soil samples were collected by Pam DeVolder from the large scale plots that had received different soil amendments. These amendments included biosolids at 50, 100 and 150 t/a, biosolids at 50+ phosphogypsum at 100 t/a, and compost in place with 50 t/a biosolids + approximately 1000 t/a wood chips. Each of the plot treatments were supposed to include lime with 10-20 t of lime per 50 t/a of biosolids. All soil analysis for this sampling effort were done at the University of Washington. Total soil metals were determined using the Aqua Regia method. In general, plant germination was poor on these plots. They had been seeded with a rye grass in July. The values presented are for the rye grass.

C:N Ratio

In addition to the sampling efforts described above, data from a set of replicated field plots and a greenhouse study will also be included. The replicated field plots were established to determine if the C:N ratio of the amendment would effect the ability of native species to reestablish on the amended areas. These plots were established in the summer of 2000 and data was first collected from them in October, 2001.

Greenhouse Study

The greenhouse study was conducted as part of a MS project by Peter Severtson. The purpose of the greenhouse study was to quantify the effects of phosphogypsum and phosphogypsum + biosolids on soil physical properties and fertility as well as on plant growth.

Results

Native grasses

The pH in the native grass plots did not reach the desired value of >7. This may be due to the complications in getting lime applied to the site by outside contractors. Despite this, plant metal concentrations were generally below levels of concern. This was not the case for Zn uptake by big blue stem and side oats gamma at the New Repository. However, plant Zn concentrations for big blue grown at Center Creek with higher total soil Zn is within acceptable levels. In general, the Cd and Pb content of the grasses are low enough to suggest that any danger to herbivores consuming these grasses is minimal. In certain cases, the Zn content of grasses is high enough to suggest some grasses may exhibit some stress. Zinc in plant tissue, however, is generally not a concern for animals consuming the forage. The sampling indicates that total metal concentrations vary widely across a relatively small area. The $Ca(NO_3)_2$ metal value is a dilute salt extractable metal. In many cases, this extract is seen as a measure of the bioavailable fraction of the total metal.

Table 1. Plant Cd concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH	Plant Cd	CaNO3Cd
Warm season	6.20± 0.28	0.45± 0.18	0.03± 0.01
Orchard Grass	5.93± 0.12	1.15± 0.37	0.05± 0.02
Big Bluestem	6.30± 0.27	0.16± 0.01	0.78± 0.18
Little Bluestem	6.57± 0.18	0.14± 0.05	0.02± 0.01
Big Bluestem Center Creek	6.41± 0.06	1.72± 0.68	0.04± 0.01
Turkey foot	5.97± 0.06	0.22± 0.04	0.03± 0.01
Indian Grass	6.00± 0.19	0.11± 0.02	0.52± 0.39
Sideoats Gama	6.07± 0.27	0.23± 0.02	0.06± 0.01
Fescue	6.12± 0.11	1.64± 1.07	0.05± 0.01
Moesby Mix	6.04± 0.15	0.15± 0.01	0.03± 0.00

Table 2. Plant and soil Pb concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH		Plant Pb		Pb total		$CaNO_3$ Pb	
Warm season	6.20±	0.28	10.93±	7.31	253±	25	0.16±	0.17
Orchard Grass	5.93±	0.12	5.44±	1.88	519±	207	0.51±	0.42
Big Bluestem	6.30±	0.27	12.96±	7.72	620±	153	0.10±	0.04
Little Bluestem	6.57±	0.18	6.85±	1.89	259±	30	-0.08±	0.01
Big Bluestem	6.41±	0.06	9.56±	4.19	766±	276	0.70±	0.23
Turkey ft	5.97±	0.06	10.80±	5.03	247±	46	0.14±	0.02
Indian Grass	6.00±	0.19	11.01±	8.36	412±	68	0.10±	0.06
Sideoats Gama	6.07±	0.27	6.38±	0.88	302±	41	0.10±	0.05
Fescue	6.12±	0.11	4.70±	0.29	711±	70	1.84±	0.80
Moesby Mix	6.04±	0.15	5.17±	1.65	292±	58	0.08±	0.04

Table 3. Plant and soil Zn concentrations for native grasses collected in July, 2001. Values and standard errors are shown for n=4.

	pH		Plant Zn		Zn total	$Ca(NO_3)_2$ Zn	
Warm season	6.2±	0.3	91±	28	725 ± 197	1.0±	0.4
Orchard Grass	5.93±	0.1	197±	53	354 ± 73	2.0±	1.0
Big Bluestem	6.3±	0.3	247±	81	1565 ± 132	100.2±	28.4
Little Bluestem	6.57±	0.2	217±	60	574 ± 107	1.1±	0.5
Big Bluestem (Center Creek)	6.41±	0.1	119±	27	4440 ± 1920	3.6±	1.5
Turkey ft	5.97±	0.1	153±	17	458 ± 123	1.2±	0.4
Indian Grass	6±	0.2	213±	34	2345 ± 1026	78.3±	63.5
Sideoats Gama	6.07±	0.3	282±	43	752 ± 67	3.0±	0.6
Fescue	6.12±	0.1	172±	76	922 ± 172	3.1±	1.2
Moesby Mix	6.04±	0.2	88±	15	489 ± 125	1.4±	0.5

Soil Treatments

There did not seem to be an obviously superior treatment amoung the soil amendments tested. Plant metal concentrations appear to be lowest in the compost and biosolids @100 plots, however, concentrations were generally acceptable across all treatments. Individual values as well as the means for each treatment are shown below. Total soil and plant P are also shown. Addition of phosphogypsum did not increase total soil or plant P.

Table 4. Soil pH, total and extractable Cd and plant Cd for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Cd	CaNO3 Cd	Plant Cd
Compost	6.45	4.0	0.04	0.63
Compost	6.45	10.0	0.03	0.65
Compost			0.03	0.56
Compost	6.51	4.3	0.05	0.55
	6.47	**6.08**	**0.04**	**0.60**
Phospho	6.11	12.2	0.06	1.19
Phospho	6.21	7.6	0.06	0.75
Phospho	6.11	20.0	0.07	0.69
Phospho	6.34	19.6	0.05	0.86
	6.19	**14.86**	**0.06**	**0.87**
BS @ 50	5.75	6.6	0.05	0.36
BS @ 50	5.52	4.3	0.06	0.41
BS @ 50	5.37	6.0	0.06	0.44
BS @ 50	5.57	7.9	0.04	0.63
	5.55	**6.19**	**0.05**	**0.46**
BS @ 150	5.73	7.5	0.04	0.56
BS @ 150	6.31	7.1	0.04	0.62
BS @ 150	6.21	7.0	0.03	0.50
BS @ 150	6.15	5.7	0.03	0.46
	6.1	**6.83**	**0.04**	**0.53**
BS @ 100	6.18	3.8	0.02	0.55
BS @ 100	6.11	15.6	0.01	0.36
BS @ 100	6.42	4.6	0.00	0.54
BS @ 100	6.17	10.2	0.01	0.72
	6.22	**8.53**	**0.01**	**0.54**

Table 5. Soil pH, total and extractable Pb and plant Pb for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Pb	CaNO3 Pb	Plant Pb
Compost	6.45	237.4	0.31	6.51
Compost	6.45	688.2	0.43	4.94
Compost			0.25	2.04
Compost	6.51	428.5	0.22	3.08
	6.47	**451**	**0.3**	**4.1**
Phospho	6.11	788.3	0.92	4.34
Phospho	6.21	613.9	0.64	3.32
Phospho	6.11	305.3	0.31	5.84
Phospho	6.34	298.7	0.36	5.28
	6.19	**502**	**0.6**	**4.7**
BS @ 50	5.75	614.3		
BS @ 50	5.52	755.6	1.27	6.09
BS @ 50	5.37	506.9	1.90	3.86
BS @ 50	5.57	224.0	0.30	2.20
	5.55	**525**	**1.2**	**4.0**
BS @ 150	5.73	375.8	0.38	1.58
BS @ 150	6.31	595.9	0.39	2.17
BS @ 150	6.21	530.3	0.41	4.02
BS @ 150	6.15	358.4	0.35	2.40
	6.1	**465**	**0.4**	**2.5**
BS @ 100	6.18	478.2	0.83	2.96
BS @ 100	6.11	510.3	0.61	4.50
BS @ 100	6.42	729.9	1.20	8.88
BS @ 100	6.17	1257.0	1.73	11.27
	6.22	**744**	**1.1**	**6.9**

Table 6. Soil pH, total and extractable Zn and plant Zn for plots receiving different soil amendments. Samples were collected in October, 2001.

Treatment	pH	Total Zn	CaNO3 Zn	Plant Zn
Compost	6.45	404.8	0.21	94.5
Compost	6.45	1210.7	0.33	85.8
Compost			1.52	97.2
Compost	6.51	467.6	0.34	83.2
	6.47	**694**	**0.6**	**90**
Phospho	6.11	677.1	1.97	166.1
Phospho	6.21	472.0	1.32	107.2
Phospho	6.11	1957.0	1.50	100.3
Phospho	6.34	1938.2	0.97	112.6
	6.19	**1261**	**1.44**	**122**
BS @ 50	5.75	611.9		
BS @ 50	5.52	959.6	0.85	138.4
BS @ 50	5.37	639.6	1.39	144.3
BS @ 50	5.57	1027.0	1.69	139.9
	5.55	**809**	**1.31**	**141**
BS @ 150	5.73	1213.6	1.48	88.1
BS @ 150	6.31	1094.0	0.81	90.5
BS @ 150	6.21	713.7	0.62	120.9
BS @ 150	6.15	662.2	0.53	98.7
	6.1	**921**	**0.86**	**100**
BS @ 100	6.18	658.7	0.60	99.0
BS @ 100	6.11	518.0	0.41	103.1
BS @ 100	6.42	1986.0	0.52	69.8
BS @ 100	6.17	658.2	0.49	82.0
	6.22	**955**	**0.50**	**88**

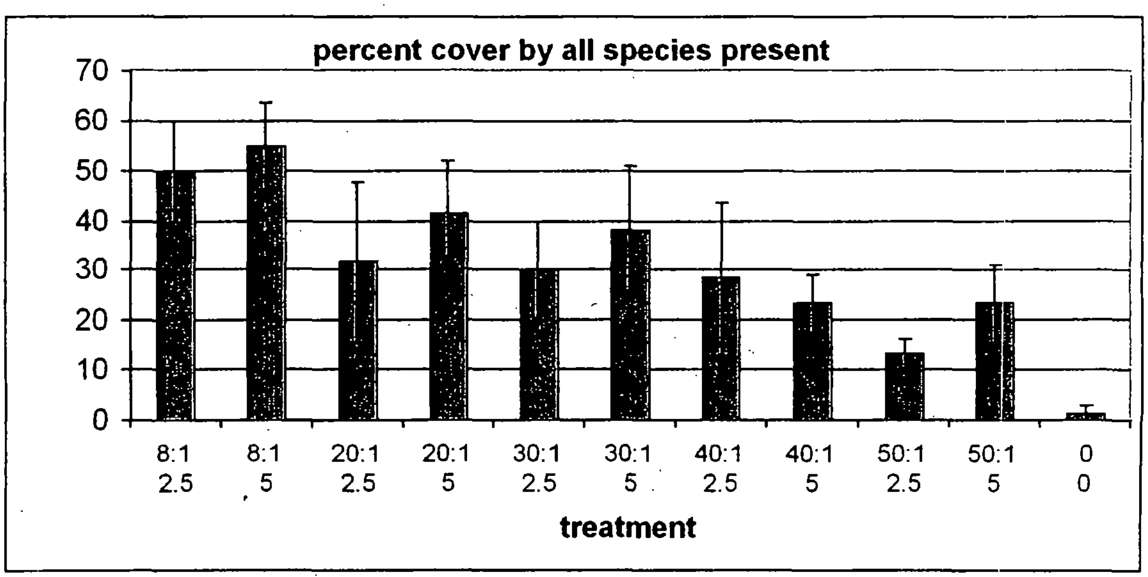
Table 7. Total soil P and plant P for plots receiving different soil amendments. Samples were collected in October, 2001.

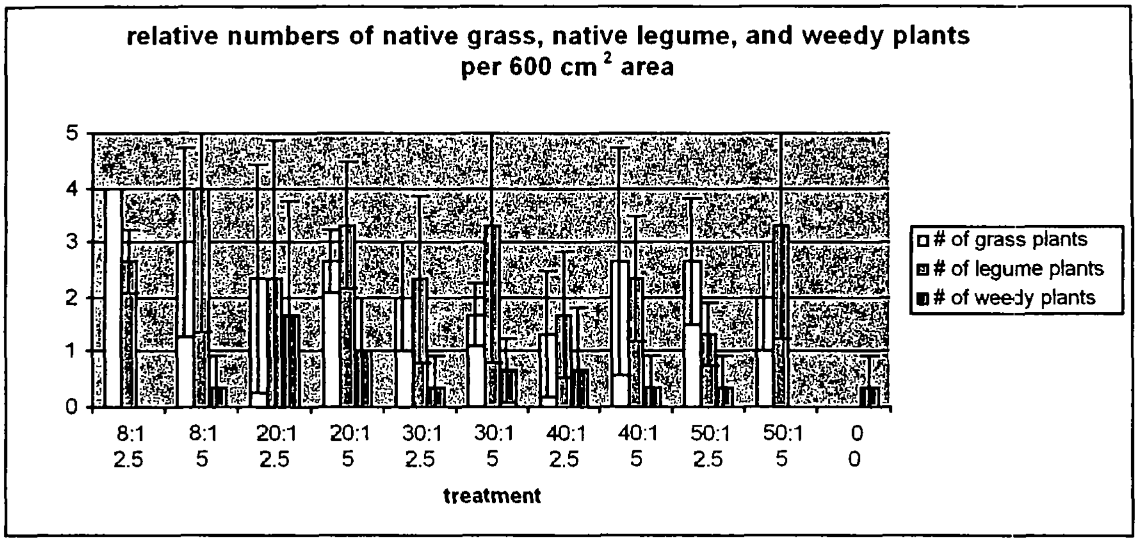
Treatment	Total P	Plant P
Compost	7575.8	7136
Compost	10117.5	5337
Compost		7862
Compost	9500.6	6460
	9065	**6699**
Phospho	6621.9	7396
Phospho	5759.9	6853
Phospho	5862.0	5522
Phospho	5922.2	7574
	6041	**6836**
BS @ 50	7234.6	
BS @ 50	7534.9	5188
BS @ 50	7331.9	4717
BS @ 50	21841.4	10223
	10986	**6709**
BS @ 150	16085.9	8565
BS @ 150	9291.1	8146
BS @ 150	9812.4	10799
BS @ 150	10968.6	6832
	11540	**8586**
BS @ 100	9577.8	6519
BS @ 100	8410.0	7610
BS @ 100	6023.5	4393
BS @ 100	5352.7	7000
	7341	**6381**

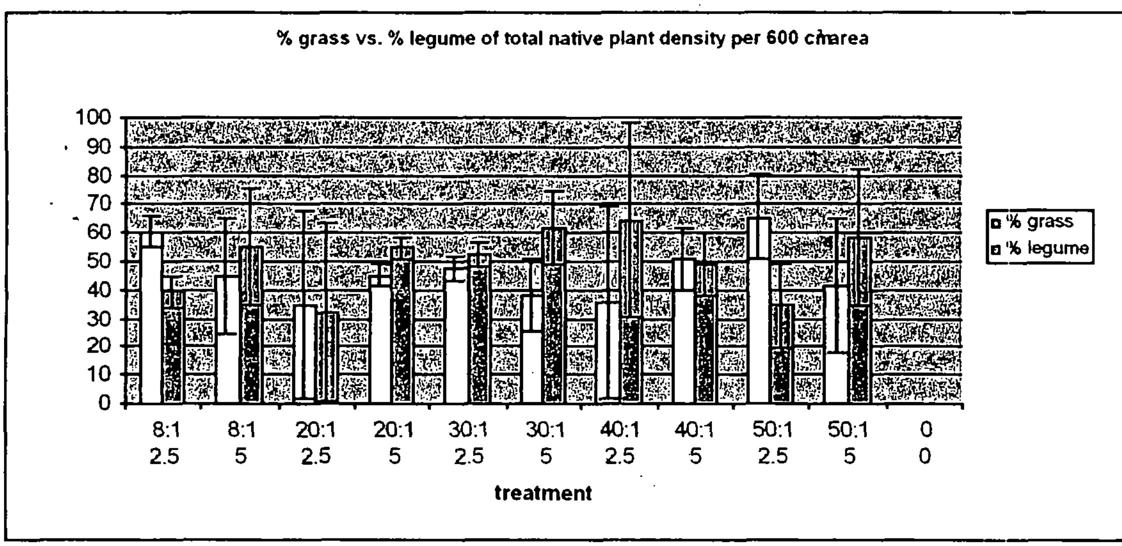
Native plant C:N ratio

Initial data from the native plant C:N study show trends rather than distinct results. Percent cover was greatest in the plots that contained primarily biosolids. The lower C:N ratio of the organic matter may provide a more fertile growing environment. However, within the same C:N ratio, higher rates of organic matter addition (5% vs 2.5% total organic matter) also showed better plant cover. This suggests that low C:N ratios with high rates of organic matter addition may provide the best initial cover for the treated areas.

It was thought that increasing the C:N ration would facilitate restoring a native cover to the treated areas. Natives are not adapted to growing in heavily fertilized soils. By increasing the C:N ratio of the amendment, it was thought that the natives would be more competitive against the invasive species. Initial results from the plots don't show a clear pattern. The data suggests that the number of legume species is increased when organic matter is added to the soil at the higher rate (5%) of addition. The C:N ratio does not seem to have a clear effect on the population of grasses vs legumes. The number of weedy plants is highest at the 20:1 carbon: nitrogen ratio. It will be important to see how survival and competition effects native populations in the next growing season.





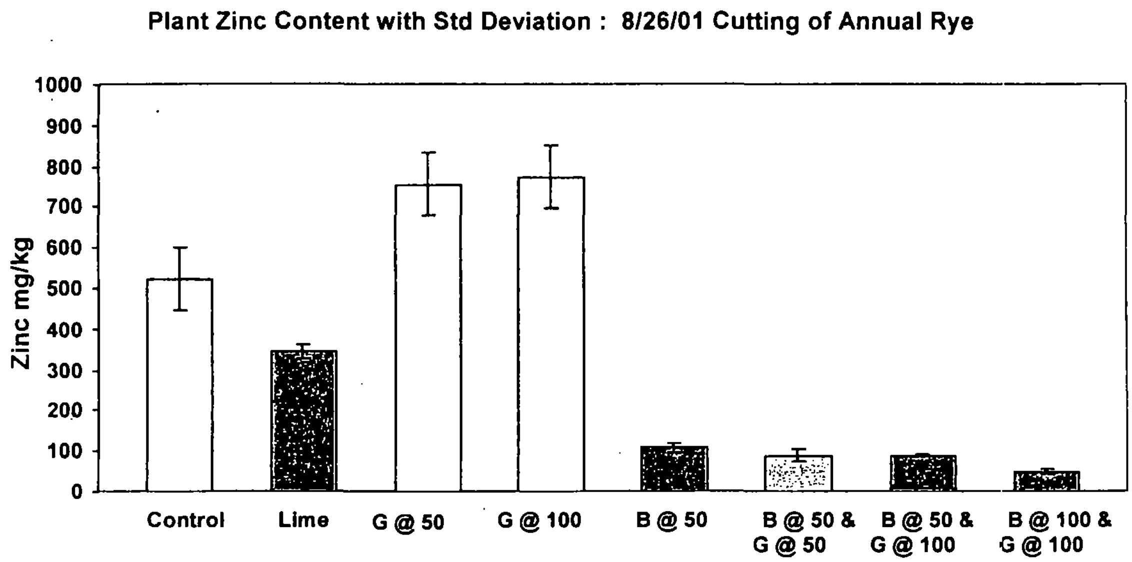


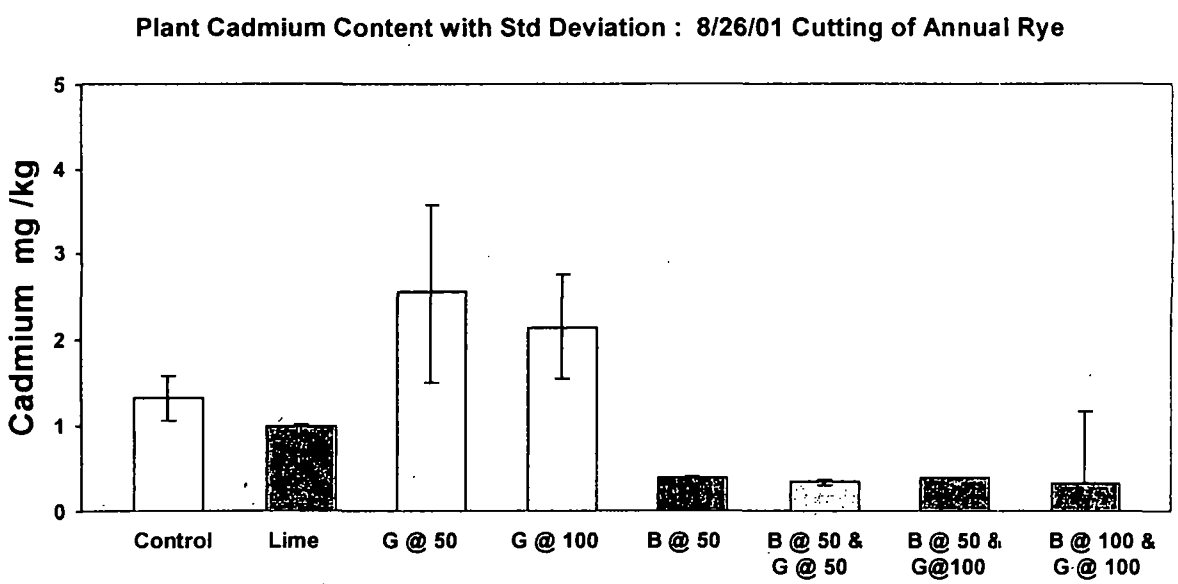
Greenhouse study

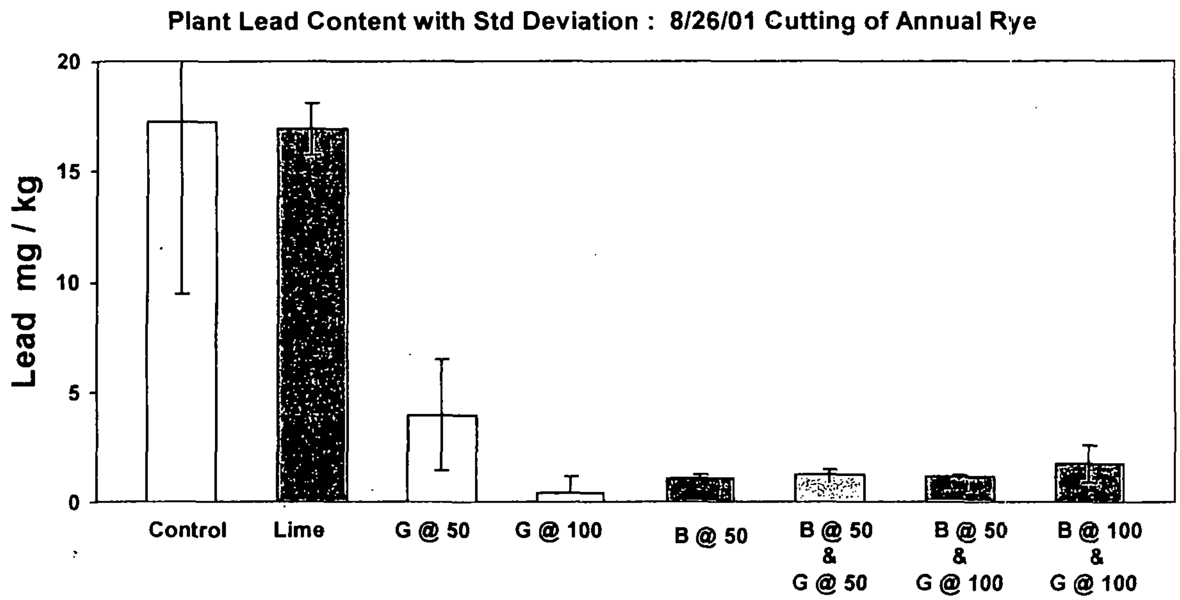
This study examined changes in soil physical properties and plant response to the addition of different rates of phosphogypsum(PG) as well as PG + biosolids to chat collected from the New Repository. All treatments except the control included limestone addition. Three cuttings of rye grass were taken before soils were analyzed for changes in fertility and physical properties. This was done to allow the amendments to stabilize and to permit the development of any soil aggregates.

Plant growth as well as plant tissue metal concentrations were best in the treatments that included biosolids. Combining biosolids with PG didn't improve growth or reduce metal uptake. Combining these amendments also did not have any apparent negative effects. Phosphogypsum does not appear to have any detrimental effects on either soil properties or plant growth when it is applied with biosolids. However, adding PG doesn't seem to improve soil properties or facilitate plant growth either. Increased water holding capacity and increased cation exchange capacity (generally used as a measure of a soil's ability to hold nutrients) appeared to be a function of increased biosolids application rate. While there may be a small increase in water holding capacity due to increased rates of PG addition, this is minor in comparison to the increases observed as a result of biosolids addition. In addition to the data provided, particle size analysis was done on the soils from the different treatments. This data hasn't been fully analyzed. However, it is expected that PG addition will increase the < 2mm size fraction of the soils.

Figure 1. Rye grass Zn (a), Cd (b) and Pb(c) concentrations for plants grown in the greenhouse on chat collected from the New Repository. These values are from the 2nd cutting of the rye grass.

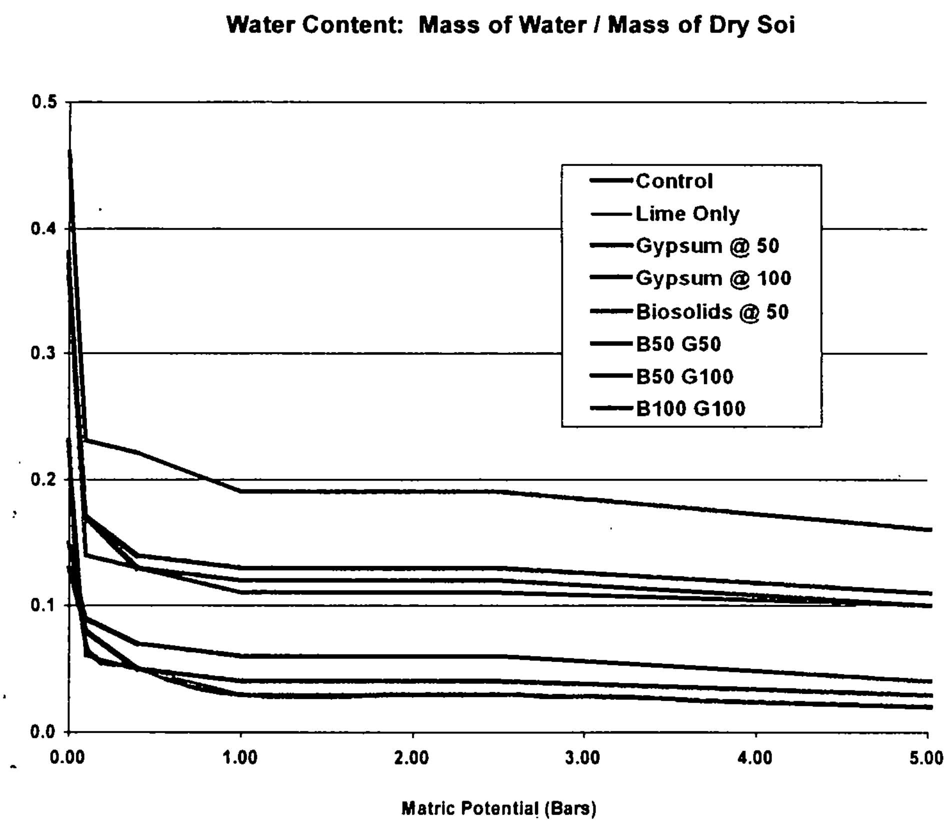






Plant Lead Content with Std Deviation : 8/26/01 Cutting of Annual Rye
Lead mg / kg
20
15
10
5
0
Control
Lime
G @ 50
G @ 100
B @ 50
B @ 50 & G @ 50
B @ 50 & G @ 100
B @ 100 & G @ 100

Figure 2. Water holding capacity of the soils from the greenhouse study.



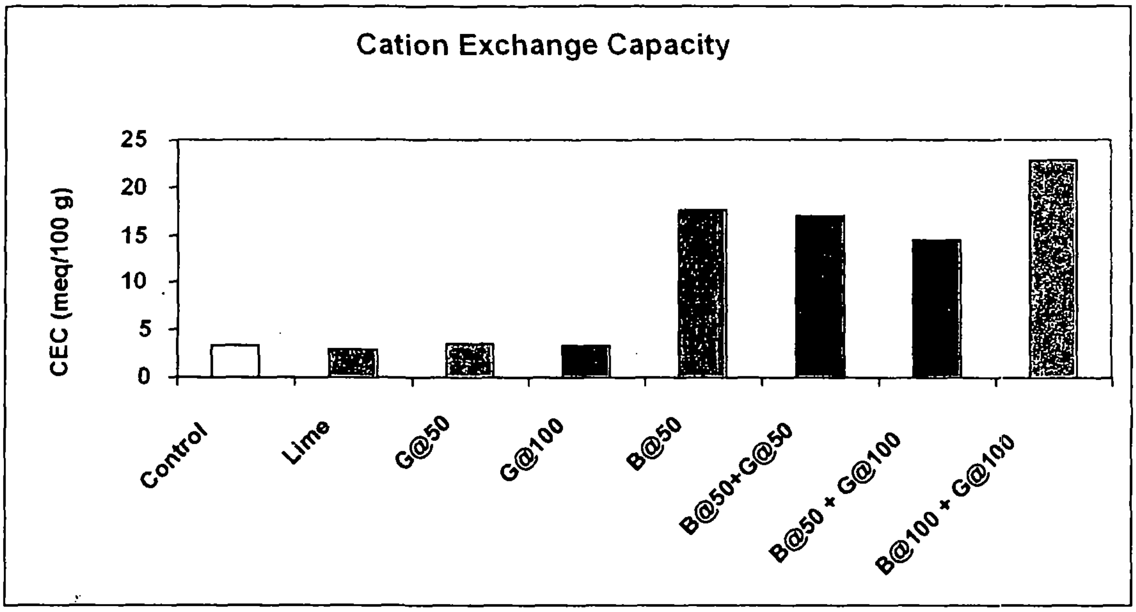


Figure 3. Cation exchange capacity of the soils from the greenhouse study.