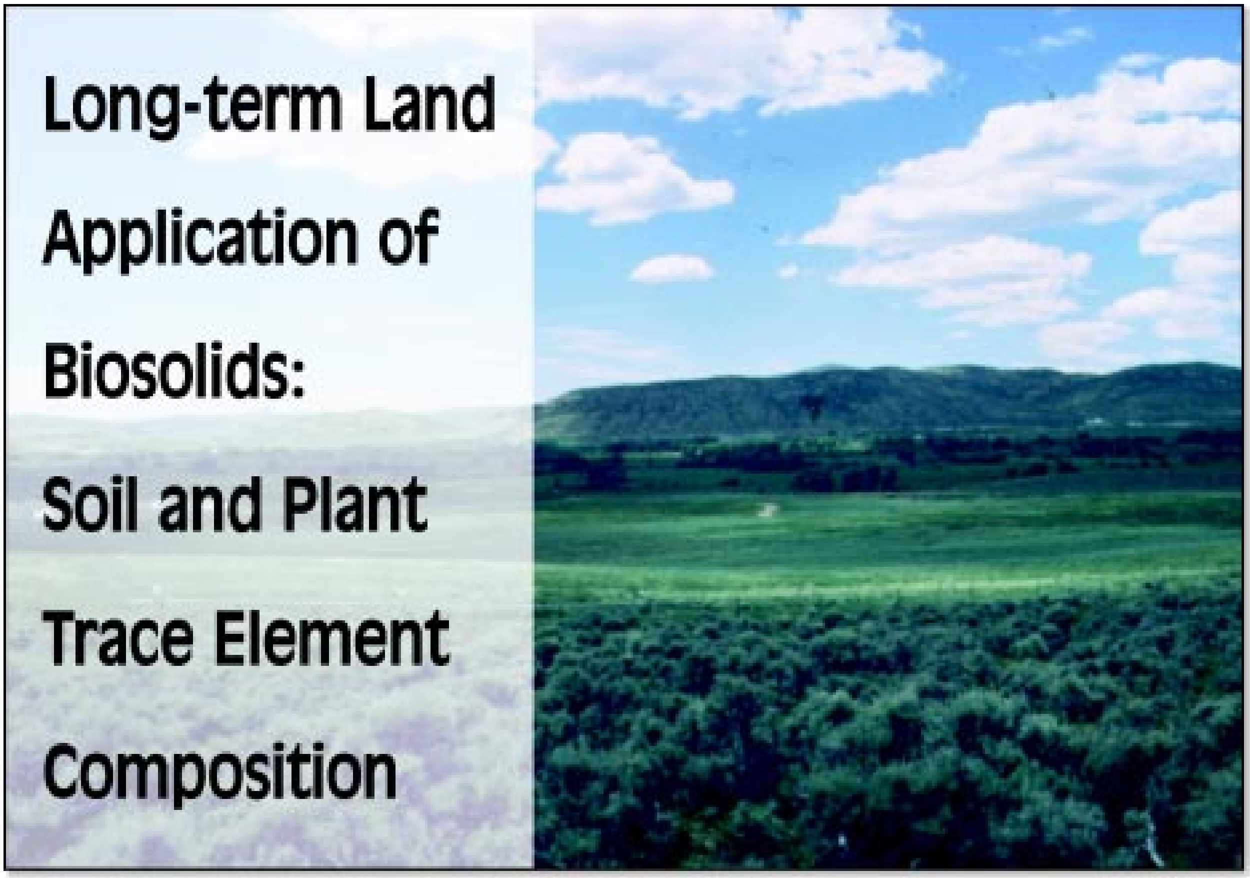
Long-term Land Application of Biosolids: Soil and Plant Trace Element Composition



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Abstract

The effect of five years of biosolids (sewage sludge) applications was evaluated at a semi-arid site in southwestern Wyoming by determining trace element (Cd, Cu, Ni, Pb, Se, and Zn) contents in soils and different grass species. Total and AB-DTPA extractable trace element contents were analyzed in soils sampled at three locations within and one location outside of the study area. Although the general trend suggested land application of biosolids increased trace element contents in the upper soil layers, only total Cu, Ni, and Pb were found to be significantly different between sites; Cd levels were below detection limit (<0.1 mg/kg) in all soils. Fifteen grass species, planted during the first year (1987) of biosolid application, were also analyzed for trace element contents. Significant differences were found with plant Cu, Se, and Zn concentrations (ANOVA); Cd levels were below the detection limit. Results of plant trace element concentrations indicated some of the wheatgrass species accumulated trace elements at levels greater than the other grasses.

Introduction

Biosolids disposal is becoming a global concern. Past traditional methods for biosolids management included disposal in landfills, incineration, and ocean dumping, all of which are currently either outlawed or becoming less popular with the public due to high costs and environmental contamination (Page and Chang, 1994). Land application is an attractive alternative to these because materials in the biosolids are recycled. Land application of biosolids can supply necessary plant nutrients, improve soil water-holding capacity, and increase beneficial microbial activity. State and federal legislation have been enacted to protect against the contamination of ground waters by chemicals derived from biosolids (Clapp et al., 1995).

Land application of biosolids is desirable because it not only decreases the space required for landfills, but recycles valuable nutrients (Pierzynski, 1994). There is also a demand from the public to recover resources from wastes, and a potential market for these resources may exist if they are of high enough quality. Land application of biosolids has been a worldwide agricultural

Table 1. Characteristics of the Evanston biosolids as determined by the Western Wyoming College Water Quality Laboratory over five years (35 samples).

Sludge parameter	Mean	Standard deviation
pH	6.27	0.47
EC S/m	1.71	21.0
Trace Elements		
Cd mg/kg	5.76	7.97
Cu mg/kg	134	114
Ni mg/kg	18.0	28.1
Pb mg/kg	106	111
Se mg/kg	2.19	0.56
Zn mg/kg	363	462

practice for many years. In 1990, the use of municipal waste composting had reduced the use of traditional landfills by 20 percent (Glenn and Riggle, 1991). This practice is effective in disposing of an otherwise waste product and recycling the nutrients found in the biosolids (Warman, 1986). Organic matter in biosolids may also benefit poorly structured and unstable soils. Biosolids can be used as an important component for reclamation of surface-mine lands due to its organic nutrient content.

Even though the primary constituents of biosolids are desirable, there are some containing potentially hazardous trace elements such as Cd, Cu, Ni, Pb, Se, and Zn (Sposito et al., 1984; Chaney, 1994). The accumulation of these trace elements in soils can increase their occurrence in plants grown on the biosolids-amended soils (Kim et al., 1988). Therefore, biosolids cannot be used indiscriminately. With proper planning and management, however, the risks involved with land application of biosolids can be essentially eliminated or reduced to acceptable levels.

The objectives of this study were to determine if five years of biosolids applications to a test site in Evanston, Wyoming, have increased soil trace element concentrations; and to determine if the different grass species grown on these biosolids-amended soils have accumulated trace elements.

Materials and Methods

Sample Collection

Soil and plant samples were collected on June 29, 1992, at the Evanston Water Treatment Plant located approximately two km west of Evanston. Biosolids from the treatment plant had been applied to the study site for five years at rates of approximately 15 dry tons per year (see Table 1 for biosolids analysis). The biosolid-treated site was located on a hill with a northeast facing slope. Soil and plant samples were collected from three different locations (lowland, midland, and upland) within the first 15 experimental plots established in 1987. A control site was also selected outside the biosolids-treated area to represent background soil elemental levels. Soils were collected at 10 cm increments to a depth of 60 cm, except for the control which was sampled to a depth of only 40 cm due to an extremely hard and dry profile. The samples were brought to the laboratory where they were air-dried, ground, and passed through a 2 mm stainless steel sieve. Soil texture was determined using the “feel method” described by Thein (1979). Plants were clipped at ground level and stored in air-tight plastic bags that were placed immediately in a cooler. The plant samples were brought to the laboratory and dried in a convection oven for 48 hours at 60 degrees Celsius. The dried plant samples were ground to 40 mesh using a Wiley Mill grinder.

Digestion and Analysis of Soil and Plant Samples

An AB-DTPA extraction was performed on the soil samples using the method of Spackman et al. (1994). The extraction solution, with an adjusted pH of 7.6, was added to the soil in a 1:4 soil:solution ratio. A total digest was also performed on the soil samples, using a modification of the Lim and Jackson (1982) method. A 0.500 g soil sample was digested in nitric, hydrofluoric, and perchloric acid at 100 degrees Celsius for 18 hours on an aluminum block digestor. Samples were diluted to 25 ml with a 1:1 HCl:water solution. A total digest of the dried plant material was done according to the method of Steward et al. (1994). A 0.500 g of dried plant sample was digested in nitric and perchloric acid at 100 degrees Celsius for two hours on an aluminum block digestor. The samples were then diluted to 35 mls with distilled, deionized water and stored in 50 ml polyethylene tubes.

The soil AB-DTPA and total digests and the plant total digests were analyzed for Se using a Varian hydride generator, model VGA-76, with a Perkin-Elmer atomic absorption spectrophotometer, model 2280 (Spackman et al., 1994, Steward et al., 1994). Cadmium, Cu, Ni, Pb, and Zn concentrations were determined on a Perkin-Elmer atomic absorption spectrophotometer, model 5000.

Statistical Analysis

Statistical analysis was performed using the computer program MINITAB, release eight (Schaefer and Farber, 1992). The ANOVA and Tukey's multiple mean comparisons were considered significant at the 0.05 level.

Results and Discussion

Soil pH

The control soil pH decreased with depth, while the general trend for the biosolids-amended soils was for pH to increase with depth (Table 2). The exception was the upland soil pH which decreased slightly from 30 to 50 cm and

Table 2. Some physical and chemical characteristics of the biosolid-amended soils from Evanston

Soil	Depth (cm)	Color	Textural class	pH	EC (dS/m)
control	0-10	7.5 YR 3/4	loam	7.88	0.39
	10-20	7.5 YR 4/4	loam	7.82	0.49
	20-30	7.5 YR 4/4	loam	7.74	0.17
	30-40	7.5 YR 4/6	loam	7.21	0.11
lowland	0-10	7.5 YR 3/4	loam	6.16	0.17
	10-20	7.5 YR 3/4	loam	6.41	2.71
	20-30	7.5 YR 4/4	loam	6.97	0.18
	30-40	7.5 YR 5/4	clay loam	7.18	1.72
	40-50	7.5 YR 5/4	clay loam	7.28	0.36
	50-60	7.5 YR 5/4	clay loam	7.91	0.29
midland	0-10	7.5 YR 3/4	loam	5.92	0.76
	10-20	7.5 YR 4/4	silt loam	6.01	0.43
	20-30	7.5 YR 4/4	silt loam	7.05	0.75
	30-40	7.5 YR 4/4	silt loam	7.72	0.41
	40-50	7.5 YR 4/4	silty clay loam	7.76	1.35
	50-60	7.5 YR 4/4	silty clay loam	7.21	0.01
upland	0-10	5 YR 3/3	silty loam	7.40	0.03
	10-20	5 YR 4/4	silty clay loam	7.65	0.02
	20-30	5 YR 4/4	silty clay loam	7.69	1.05
	30-40	5 YR 4/4	silty clay loam	7.28	1.03
	40-50	5 YR 4/6	silty clay loam	7.21	0.13
	50-60	5 YR 4/6	silty clay loam	7.41	0.30

Table 3. Total soil trace element concentrations.

Soil	Depth (cm)	Cu mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Zn mg/kg
control	0-10	17.1	4.0	27.9	0.2	43.9
	10-20	13.5	11.9	31.9	1.5	40.4
	20-30	55.0	8.8	33.5	0.4	31.5
	30-40	48.2	8.9	36.0	0.7	25.7
lowland	0-10	62.6	8.5	40.0	0.4	58.1
	10-20	51.9	14.5	36.4	1.7	65.4
	20-30	67.5	14.5	45.1	2.2	78.1
	30-40	59.6	16.5	40.8	0.7	49.6
	40-50	54.2	18.6	43.1	0.5	41.6
	50-60	75.1	23.5	41.1	0.8	35.5
midland	0-10	29.5	21.5	46.0	0.3	78.5
	10-20	34.0	20.5	41.5	0.3	66.4
	20-30	61.0	30.5	43.0	1.6	62.0
	30-40	59.4	23.5	45.4	0.8	58.9
	40-50	60.5	23.0	38.5	0.5	56.5
	50-60	59.5	28.0	34.0	0.6	53.8
upland	0-10	89.8	26.9	35.4	0.6	75.3
	10-20	80.0	26.5	33.0	1.1	34.5
	20-30	70.6	30.0	34.3	2.6	26.8
	30-40	42.9	32.9	37.9	0.8	24.0
	40-50	73.5	33.0	36.0	0.4	22.0
	50-60	21.9	29.9	43.4	0.4	23.9

then increased in the 50 to 60 cm depth; a pH decrease was also determined in the 50 to 60 cm depth sample of the midland soil. The pH values of the upper 30 cm of the biosolids-amended soils were all less than that of the control soil; however, the pH of the lower horizons of the sludge amended soils were similar to those of the control soil, suggesting the sludge treatments reduced pH levels of the upper 30 cm of the soil profiles.

Soil EC

The EC of the control soil increased slightly in the 10 to 20 cm depth soil followed by a decrease with deeper samples (Table 2). The biosolids-amended soils also had zones lower in the profile which had elevated EC values. The areas of these elevated salts coincided with changes in soil texture (Table 2). As expected, the salts increased when soil particle size decreased. The lowland soil had the highest EC of all the samples. This was a result of irrigation water that leached salts from the biosolids horizontally, as well as vertically down slope, resulting in an accumulation in the lowland soils.

Soil Element Concentrations

No Cd was detected in either total digested samples or the AB-DTPA soil extracts. This result was anticipated as the biosolids applied to the study area contained very low Cd concentrations (Table 1).

Total soil Cu concentrations were somewhat variable in the individual profiles (Table 3). The AB-DTPA extractable Cu, however, showed a definite increase in Cu within the upper 10 cm of all biosolids-amended soils (Table 4). The control soil had the highest AB-DTPA Cu level in its 10 to 20 cm depth. Organic compounds added with the biosolids increased soluble Cu contents (Kabata-Pendias and Pendias, 1992), which explained the difference between the control and sludge amended soils.

The general trend for the total Ni concentrations in each soil profile was to increase slightly with depth (Table 3). The distribution of Ni in a soil profile is related to clay fractions (Kabata-Pendias and Pendias, 1992); the higher the clay content, the greater the accumulation of Ni. The percent clay in the soil profiles increased with depth, as did the total Ni concentrations. Others have reported that Ni tends to accumulate in arid and semi-arid soils (EPA, 1995). The sludge-amended soils had been irrigated over the course of the study, which may have resulted in leaching of Ni to lower depths.

The AB-DTPA extractable Ni concentrations of the control and upland soils were generally lower than those of the midland and lowland soils (Table 4). Lower Ni concentrations in the control soil were expected as no Ni was added through biosolids amendments; lower Ni concentrations of the upland soil were probably due to Ni being relatively soluble and capable of being leached (Kabata-Pendias and Pendias, 1992). Therefore, Ni added by the sludge to the upland soil solution may have been leached downslope to the midland and lowland soils, increasing their Ni concentrations.

The general trend for the AB-DTPA extractable Ni within the individual soil profiles was for Ni to decrease with depth (Table 4). These available Ni reductions with depth may have been due to soil pH as the pH of the biosolids-amended soils increased with depth. It has been shown that soils with higher pHs and CECs have higher potentials for fixing Ni in forms less soluble than in soils with lower pH and CEC (Abdel-Sabour, 1991).

The total Pb concentrations of the soils were basically uniform throughout the soil profiles (Table 3). Because of the leaching due to the addition of irrigation waters, Pb from biosolids was higher in midland and lowland soils than the upland and control soils.

Table 4. Concentrations of AB-DTPA extractable trace elements.

Soil	Depth (cm)	Cu mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Zn mg/kg
control	0-10	2.3	0.4	1.5	0.02	1.3
	10-20	2.8	0.2	0.8	0.02	0.4
	20-30	1.9	0.2	0.9	0.06	0.4
	30-40	1.2	0.3	0.5	0.10	0.6
lowland	0-10	5.1	1.6	1.9	0.04	5.4
	10-20	2.9	1.3	1.3	0.01	1.5
	20-30	2.4	0.8	1.3	0.02	0.5
	30-40	3.3	0.4	1.2	0.02	0.5
	40-50	2.0	0.1	1.1	0.05	0.6
	50-60	1.5	0.1	1.0	0.01	0.4
midland	0-10	8.1	0.8	3.8	0.03	11.9
	10-20	3.1	1.5	1.1	0.02	0.8
	20-30	3.0	1.0	1.1	0.03	0.9
	30-40	3.2	0.3	1.2	0.01	1.6
	40-50	3.8	0.3	1.4	0.03	0.6
	50-60	3.5	0.1	1.4	0.10	1.1
upland	0-10	8.0	0.6	2.5	0.02	10.3
	10-20	2.5	0.2	0.9	0.02	0.8
	20-30	1.7	0.2	0.7	0.02	0.4
	30-40	1.2	0.3	0.7	0.02	0.7
	40-50	0.8	0.2	0.5	0.09	0.3
	50-60	0.8	0.2	0.6	0.02	0.3

All four soils had higher AB-DTPA extractable Pb concentrations in the top 10 cm than in the lower portion of their profiles (Table 4). The general trend was for extractable Pb to decrease with depth, except for the midland soil, which had a slight increase in Pb within the 40 to 60 cm depth. This accumulation of Pb in the surface horizons was anticipated since Pb is generally the least mobile of the heavy metals (Kabata-Pendias and Pendias, 1992). Because of this, little Pb would have been leached down to the lower horizons or from upland to lowland sites.

Table 5. Means of the total soil trace element concentrations. [1]

Soil	Cu mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Zn mg/kg
control	33.5a	8.4a	32.3a	0.7	35.4
lowland	53.5b	16.0b	41.1b	1.1	54.7
midland	50.7b	24.5b	41.4b	1.5	62.7
upland	63.1b	29.9b	36.7ab	1.9	34.4

[1] Means within each column followed by a different letter are significantly different at $\alpha = 0.05$, Tukey's multiple mean comparison, degrees of freedom = 18 and n = 6 for all soils except the control in which n = 4.

The general trend in total Se was an accumulation in the 10 to 30 cm region of the profiles (Table 3). AB-DTPA extractable soil Se concentrations were also highest in the lower portion of the profiles (Table 4). This increase lower in the profile was expected because the pH of the soils increased with depth, where insoluble Se forms could be converted to more soluble Se species (Johnsson, 1991).

The Zn concentrations of the control soil were lower than those of the sludge-amended soils (Table 3). This result was expected as the sludge itself contains an average Zn level of 363 mg/kg. A decrease in AB-DTPA extractable Zn was found with depth within the soil profiles (Table 4); however, the control soil had the lowest Zn content in the surface horizon. The decrease in soluble Zn with depth in the sludge-amended soils was probably due to Zn mobility at low pH (Sims and Patrick, 1978). The lower pH at the surfaces of the sludge-amended soils explained the elevated Zn concentrations. A study performed by Milner and Barker (1989) also indicated the lower the pH of the soil, the greater Zn availability. Another reason for the decrease with depth in soluble Zn was the change in soil texture. Increases in clay percentages decreased the available Zn, due to Zn binding to the clay particles (Pepper et al., 1983).

A Tukey's multiple mean comparison of total trace element concentrations indicated the control soil had significantly lower Cu and Ni concentrations than those of the biosolids-amended soils (Table 5). In addition, the mean comparison test also indicated the lowland and midland soils had significantly greater Pb concentrations than did the control soil (Table 5). A Tukey's multiple mean comparison of the means from each soil profile indicated there were no significant differences among the mean AB-DTPA extractable trace element concentrations for each soil profile.

Plant Element Concentrations

An ANOVA on each plant element concentration, based on the location of the sample with regards to slope, indicated there were no significant differences for any of the elements (Table 6). The ANOVA on mean plant species concentrations, however, did suggest there were significant differences for plant Cu, Se, and Zn (Tables 7). A Tukey's multiple mean comparison for these elements indicated Ephraim crested wheatgrass had the highest Cu concentration, Oahe wheatgrass had the highest Se concentration, and Fairway crested wheatgrass had the highest Zn concentration. The other wheatgrasses also had higher concentrations of these elements. These results

Table 6. Plant trace element concentrations.

Plant name	Location	Cu mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Zn mg/kg
Manchar Smooth Brome	lowland	20.6	4.25	12.8	0.39	20.6
	midland	14.1	9.24	17.6	0.17	23.3
	upland	30.4	7.78	24.8	0.42	45.3
Regar Brome	lowland	18.4	7.76	18.4	1.1	36.7
	midland	24.2	6.40	24.2	0.49	42.0
	upland	24.5	5.19	23.5	0.82	34.6
Bozoisky Russian Wild Rye	lowland	14.0	4.21	27.1	0.31	27.4
	midland	13.3	5.59	21.0	0.41	24.5
	upland	13.5	2.13	34.9	0.48	40.6
Swift Russian Wild Rye	lowland	15.1	9.83	23.9	0.49	27.1
	midland	14.7	5.61	23.9	0.36	25.3
	upland	16.9	7.06	20.6	0.27	24.6
Altai Russian Wild Rye	lowland	12.5	20.3	28.5	0.47	34.2
	midland	10.6	12.7	17.0	0.09	29.0
	upland	15.7	7.83	24.2	0.62	42.0
Rosana Western Wheatgrass	lowland	14.1	12.0	13.4	0.02	22.6
	midland	21.0	4.90	37.1	0.33	41.3
	upland	19.7	4.22	34.4	0.26	31.6
Hycrest Crested Wheatgrass	lowland	19.8	4.23	30.3	0.33	52.9
	midland	26.8	1.41	16.2	0.04	38.7
	upland	30.8	11.6	18.5	0.08	48.5
Fairway Crested Wheatgrass	lowland	22.6	5.65	31.8	0.28	66.3
	midland	29.6	4.93	33.1	0.44	95.1
	upland	20.3	22.1	25.9	0.03	48.7
Ephraim Crested Wheatgrass	lowland	38.0	4.84	24.9	0.81	49.8
	midland	48.4	9.21	16.6	0.56	68.2
	upland	37.4	10.6	18.4	0.45	52.2
Oahe Wheatgrass	lowland	21.5	4.27	15.2	1.3	32.8
	midland	22.7	7.08	22.0	1.0	42.5
	upland	16.3	7.79	17.0	0.21	39.7
Luna Pubescence	lowland	14.7	7.01	28.1	0.26	29.5
	midland	21.3	7.11	17.8	1.4	52.6
	upland	24.2	8.76	27.7	0.54	50.9
Blue Bunch Wheatgrass	lowland	24.1	11.3	19.1	0.22	34.0
	midland	23.5	10.4	20.7	0.81	43.5
	upland	47.2	5.86	25.2	0.25	38.7
Wheatgrass Hybrid	lowland	11.9	1.40	10.5	0.19	23.8
	midland	31.0	7.04	36.6	0.33	43.0
	upland	17.0	2.48	12.0	0.32	28.3
Big Blue Grass	lowland	24.9	5.05	29.2	0.39	34.9
	midland	30.4	2.83	14.9	0.69	43.8
	upland	21.7	7.68	15.4	0.87	29.3
Fawn Tall Fescue	lowland	22.5	3.52	12.1	0.38	41.6
	midland	18.3	12.0	16.2	0.09	36.6
	upland	18.0	9.51	22.5	0.24	29.6

Table 7. Mean concentrations of plant trace elements. [1]

Plant name	Cu ug/kg	Ni ug/kg	Pb ug/kg	Se ug/kg	Zn ug/kg
Manchar Smooth Brome	21.7bc	7.1	18.4	0.3b	29.6b
Regar Brome	22.4bc	6.5	22.0	0.8ab	37.7ab
Bozoisky Russian Wild Rye	13.6c	4.0	27.6	0.4b	30.8b
Swift Russian Wild Rye	15.6bc	7.5	22.8	0.4b	25.7b
Altai Russian Wild Rye	12.9c	13.6	23.2	0.4b	35.0b
Rosana Western Wheatgrass	18.3bc	7.1	28.3	0.2b	31.9b
Hycrest Crested Wheatgrass	25.8abc	5.8	21.7	0.2b	46.7ab
Fairway Crested Wheatgrass	24.2abc	10.9	30.2	0.3b	70.0a
Ephraim Crested Wheatgrass	41.3a	8.2	20.0	0.6ab	56.8ab
Oahe Wheatgrass	20.2bc	6.4	18.0	1.2a	38.3ab
Luna Pubescent	20.1bc	7.5	24.5	0.7ab	44.3ab
Blue Bunch Wheatgrass	31.6bc	9.1	21.7	0.4ab	38.7ab
Wheatgrass Hybrid	20.0bc	3.6	19.7	0.3b	31.7b
Big Bluegrass	25.7abc	5.3	19.8	0.6ab	46.0ab
Fawn Tall Fescue	19.6bc	8.3	16.9	0.4b	35.9ab

[1] Means within each column followed by a different letter are significantly different at $\alpha = 0.05$, Tukey's multiple mean comparison, degrees of freedom = 30 and n = 3.

suggest some of the wheatgrass species can accumulate trace elements under the conditions of the present study.

Trace element bioavailability resulting in plant uptakes that cause a significant reduction in yields is important to consider when developing a biosolids application program. Although the trace element levels found in grasses of this study did not exceed thresholds for concern (Chaney 1994), they did point to the fact that there is differential trace element uptake by the grasses examined. Therefore, soil-plant interactions, as well as environmental conditions, should be evaluated when developing a program involving the land application of biosolids.

Summary and Conclusion

The results of the soil analysis indicated that biosolids-amended soils had significantly greater total Cu, Ni, and Pb concentrations. Plant trace element analysis indicated wheatgrass plants generally accumulated higher concentrations of all trace elements, although not at levels of concern. Three different wheatgrass hybrids, Ephraim crested wheatgrass, Oahe wheatgrass, and Fairway crested wheatgrass, accumulated significantly greater amounts of Cu, Se, and Zn, respectively. These results indicate that perhaps the wheatgrass species accumulate higher concentrations of the trace elements than the other species included in this study.

The results of this study suggest land application of biosolids can increase trace element concentrations in soils and plants. When planning land application of biosolids, caution must be exercised to prevent hazardous levels of trace elements from occurring in soils as well as plants grown on these soils. Such factors as soil type, pH, EC, the topography of the land, and the plant species to be grown must all be considered.

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