REGRESSION ANALYSIS TO PREDICT SELENIUM LEVELS AT TWO SURFACE COAL MINES IN THE POWDER RIVER BASIN, WYOMING[1]

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Abstract: Selenium (Se) is an element of interest in plant and animal nutrition because of the narrow range between essential and toxic levels. Many areas being mined in the Powder River Basin of northeastern Wyoming contain pockets of high Se concentrations within the overburden material. Therefore, it has become increasingly necessary for industry and state regulatory personnel to try to quantify relationships between pre-existing soil Se levels to post-mining levels in both soils and plants. A study was initiated in 1991 to investigate the relationship of plant Se uptake and soil/backfill Se levels at two active coal mines in the Powder River Basin, Wyoming. Soil and vegetation samples were collected in 1991 and 1992. Soil/backfill Se levels were determined by five methods: total Se and hot water, AB-DTPA, saturated paste, and dihydrogen phosphate extractable Se. Total plant Se was also determined. Plant Se levels of four vegetation lifeforms were regressed on eleven soil variables to construct appropriate models for assessing plant-soil Se relationships. These regression analyses were conducted with soil depth, vegetation type (native versus reclaimed), and mine (large mine (Mine L) and (small mine (Mine S)) as important subcategories. Depth and type were significant in determining statistical relationships. Simple linear regression models were developed, but the majority of the slopes were not significantly different at the 0.05 probability level. Multiple linear regression models revealed that soil Se and pH were the most important predictors of plant Se levels for native areas; no specific parameter was dominant in reclaimed area analysis. The R^2's for native areas were improved over the multiple linear models by deriving polynomial regression models. Polynomial regression models for the reclaimed areas resulted in marginal improvement of R^2 values over the multiple linear regression models. Whereas hot water soluble Se appears to be a better predictor of plant Se concentrations, both AB-DTPA and phosphate extractable Se were also good predictors. The best statistical relationships were also determined with depths 2 and 3 of native areas. Inclusion of age of reclamation, however, improved the polynomial models for reclaimed areas.

Additional Key Words: Soil-plant selenium relationships, regression models, predictive models.

Introduction

One of the most elusive elements in nature is selenium (Se), especially in determining its bioavailability to plants, which may depend on a number of soil parameters, vegetation considerations, and climatic factors. Due to increased mining activity in the Powder River Basin of northeastern Wyoming, industry and state regulators have become concerned about identifying pre-mining Se levels in soil or overburden that may result in increased levels in plants grown on reclaimed areas. Therefore, one of the major purposes of this study was to determine the statistical relationship between soil Se levels and plant Se concentrations on native and reclaimed areas at two mines within the Powder River Basin of Wyoming. This information may eventually be used by industry and state regulatory personnel in determining specific mine backfill handling procedures within the Powder River Basin.

This paper will primarily focus on the regression modeling results of the 1991 sampling program of an Abandoned Coal Mine Land Research project, and the subsequent validation by the 1992 sampling program. The four lifeforms examined in this study included: grass, forb, shrub, and composite grass. Nine independent variables included: soil depth, pH, EC, SO_4, total soil Se, hot water extractable soil Se, AB-DTPA extractable soil Se, saturated paste soil Se, and dihydrogen phosphate extractable soil Se. In addition to these independent variables, mine site and type of vegetation (i.e., native vs. reclaimed) were also included in the statistical analysis.

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Materials and Methods

Selection of Independent Variables

Selection of the independent variables was based on past findings of various researchers (Trelease and Beath, 1949; Rosenfeld and Beath, 1964; Ihnat, 1989). The following parameters were selected for this study: pH; electrical conductivity (EC); sulfate (SO_4); total soil Se (tse); hot water soluble soil Se (hwse); AB-DTPA extractable soil Se (abcse); saturated paste soil Se (spse); and dihydrogen phosphate extractable Se (hpse). Selection of pH, EC, and SO_4 were based, in part, on Arvy (1992), Banuelos (1990), and Severson and Gough (1992), respectively. In addition, anticipated controlling factors within the local environment such as vegetation type, mine, and soil/backfill depth were also included in the statistical analysis.

Field Sampling

Soil and vegetation were sampled on native and reclaimed areas within two active mine sites. A total of 23 native (13 from the large active mine (Mine L) and 10 from the small active mine (Mine S) and 79 reclaimed (71 from Mine L and 8 from Mine S) reclaimed areas were sampled during 1991. Twenty-three and 52 native and reclaimed area sites, respectively, were sampled in 1992 for vegetation, with soil sampled at a subset of these sites. Actual 1991 soil sample numbers consisted of approximately 520, with the exception of AB-DTPA, which was approximately 905; 1991 vegetation sample numbers for composite grass (Comg), Grass, Forb, and Shrub were 84, 89, 72, and 36, respectively. Approximately one-fourth as many soil samples were collected in 1992 as collected in 1991; 1992 vegetation sample numbers were similar to 1991.

Within native areas, soils were sampled by horizon to a maximum depth of 1.5 m. Statistical analysis was conducted on approximate weighted average values, determined as a percent of overall depth, within native areas, and consisting of the following: depth 1) 0 - 0.3m; depth 2) 0.3 - 0.6m; depth 3) 0.6 - 0.9m; depth 4) 0.9 - 1.2m; and depth 5) 1.2 - 1.5m.

Within reclaimed areas, soils were sampled based on topsoil replacement depth, and 0-1.2 m of the underlying backfill material. Depths used for statistical comparisons within reclaimed areas consisted of the following: depth (1) replaced topsoil (approximately 0.6m); depth (2) 0 - 0.6m of regraded backfill; and depth (3) 0.6 - 1.2m of regraded backfill.

Vegetation samples were collected from the various lifeform categories present at each sample point, chilled in the field, and frozen within ten hours of collection. Individual plant species that were collected for total Se analysis were based on those species with the highest percent cover based on the following categories: <1, 1-10, 11-25, 26-50, 51-75, and 76-100. The majority of sampled species included, in part: *Agropyron smithii*, western wheatgrass (currently *Elymus smithii*); *Medicago sativa*, alfalfa; *Ratibida columnifera*, prairie coneflower; *Artemisia tridentata*, big sagebrush; and *Artemisia frigida*, fringed sagewort.

Laboratory Analysis

All soil samples were processed and analyzed for the nine independent variables mentioned earlier. Specific methodology for individual Se extracting parameters followed the initial draft and final standard operating procedures outlined by the Wyoming Land Quality Division (Spackman et al., 1992, 1994). All plant samples were processed and analyzed for total Se within the four lifeform categories mentioned earlier, following the methods outlined by Steward et al. (1994).

Statistical Analysis

Regression analysis was initiated by first developing simple linear regression models for levels of plant Se on levels of soil Se based on whether depth, mine, and type were important considerations. Only differences in slope were tested since it was assumed that intercepts would vary by depth. To test for the importance of soil depth with respect to mine and vegetation type, variables were established to develop comparative regression models by using the F test for arbitrary y-intercepts, parallel slopes (Weisberg, 1985). Testing was done to determine the relationship between plant uptake of Se and various soil parameters, which included soil Se, i.e., the relationship as determined by slope. The calculated F ratio was then compared to a tabulated F value at the 0.05 type I error level. These F tests were separately conducted for Comg, Grass, Forb, and Shrub, and for each of five soil Se analytical methods: tse, hwse, abcse, spse, and hpse (i.e., independent variables). Separate F tests were also conducted for vegetative type and mine differences to determine whether data could be combined over native/reclaimed and Mine L/Mine S.

Multiple regression model building was initiated after the simple models to further explore the relationship between soil Se and plant Se levels. Additional soil parameters such as pH, EC, and SO_4 were included in the multiple regression models. The C_p statistic was then derived on all possible models (Weisberg, 1985). Those models in which the C_p statistic was small and approached p (the number of parameters in the model) without exceeding it were noted and used to determine the necessity of coefficients for the independent variables.

Polynomial models consisting of additional squared and cross product parameters were determined for native and reclaimed areas using plant lifeform Se levels, soil Se concentrations, and depth. The best models were selected based on significance of parameters at $p=0.05$ and R^2 for each of the combined variables mentioned.

The 1991 simple regression models were validated using 1992 data. Using these models, plant Se level were predicted. Predicted levels were then regressed on the observed plant Se levels, separately by vegetation type. The slopes and R^2 values were tested for significant difference from zero ($p \leq 0.05$) using a t test (Neter, et al., 1990). In addition, t tests were performed on the resulting comparison to determine if slopes were also significantly different from 1. This last test was used to show how well the 1992 predicted values compared to the 1992 observed, i.e., if the relationship was 1:1.

Age of reclaimed area was also considered an independent variable in additional polynomial regression analysis. In addition, reclaimed areas were broken out into relative ages (1979-1985 and 1986-1991), which corresponded to the year the area was reclaimed.

Results

Depth was a significant factor in many of the statistical analyses, particularly within native sites. Depth of soil sampling, therefore, cannot be ignored when assessing soil-plant Se relationships, at least if one is sampling in native areas. In addition, differences across depths appeared to be most important at Mine L and for the lifeform category shrub, a fact which may be related to the distribution of the shrub roots within the soil profile.

Vegetation type was also a significant factor in the analysis, which would generally indicate that separate regression models should be developed for native and reclaimed areas. The four foot layer of backfill material that comprised Depth 2 and 3 on reclaimed areas was analyzed separately from Depth 1, which is the replaced topsoil. Differences across vegetation type appeared to be most important between combined reclaimed Depths 2 and 3 and Depth 1 of the reclaimed areas. This is likely due to the relative young age of most sampled reclaimed areas and the fact that the young root systems of most seeded species have not penetrated into the backfill.

Mine was generally not considered a significant factor in the statistical analyses indicating that, by depth, the Mine L information could be combined with Mine S by vegetation type (native versus reclaimed) and depth. Differences across mines appeared to be most important in native areas at Depth 5 and for the lifeform category Comg. This is likely a result of the topographic extremes between native areas at the two mine sites. Mine S has more broken and varied topography with more shallow soils than Mine L.

Simple regression models were used to determine possible relationships between total or extractable soil level Se and total plant Se. R^2 values were generally low for both native and reclaimed areas, although the values for reclaimed areas were much lower than those for native values. No total Se (tse) R^2 values were greater than 0.50 indicating that tse is a poor predictor of plant Se. Hot water extractable Se and abcse generally showed the highest R^2 values for all four lifeform categories followed by hpse. Saturated paste Se (spse) generally displayed poor relationships, with most values less than 0.50. All R^2 values greater than 0.50 were for native areas, generally for depths 2 and 3 (Table 1).

Table 1. Simple regression summary ($R^2 > 0.50$, $p \leq 0.05$) for native site plant Se regardless of mine.

Lifeform	Depth	Extractant	Soil Se	Intercept	R^2	Degrees of Freedom
Composite	2	hwse	7.08	0.37	0.70	50
Grass	2	abcse	6.07	0.28	0.72	51
	2	hpse	4.15	0.06	0.60	48
	3	hwse	3.87	0.36	0.62	50
	3	abcse	4.00	0.28	0.58	50
	3	spse	6.42	0.34	0.59	47
	4	hwse	3.95	0.24	0.62	47
	4	abcse	3.81	0.19	0.55	47
	5	hwse	4.36	0.24	0.50	40
Grass	2	hwse	8.46	0.36	0.60	53
	2	abcse	7.32	0.24	0.63	54
	2	hpse	4.94	-0.01	0.52	51
	3	hwse	4.83	0.32	0.58	53
	3	abcse	4.94	0.22	0.53	53
	3	spse	8.03	0.28	0.56	50
	4	hwse	5.25	0.16	0.59	50
	4	abcse	5.06	0.08	0.52	50
Forb	2	hwse	18.82	0.36	0.51	36
	2	abcse	16.71	0.05	0.54	36
	3	hwse	11.38	0.10	0.52	35
	3	spse	18.77	0.17	0.51	32
	4	hwse	13.65	-0.61	0.55	32
Shrub	2	hwse	16.51	0.22	0.79	50
	2	abcse	13.62	0.05	0.74	51
	2	hpse	9.46	-0.43	0.64	48
	3	hwse	7.85	0.32	0.52	50

Statistical significance of each parameter included in the full multiple regression model were also conducted. Electrical conductivity and SO_4 did not play a significant role in the multiple regression models and were deleted from the full model.

The reduced multiple regression models that included soil Se and pH had fairly high R^2 values ($R^2 \geq 0.50$) for the native areas but not the reclaimed areas. Models for native areas producing R^2 values greater than 0.50, for all parameters that were significant at $p \geq 0.05$ are listed in Table 2. The highest R^2 values generally were derived from regressing plant Se on hwse and abcse by type and depths 2 and 3.

Table 2. Basic multiple regression summary ($R^2 > 0.50$, $p \leq 0.05$) for native areas by lifeform regardless of mine.

Lifeform	Depth	Extractant	Soil Se	pH	Intercept	R^2	Degrees of Freedom
Composite	1	hpse	4.63***	0.87***	-6.35***	0.52	47
Grass	2	tse	0.67**	0.84***	-6.26***	0.51	47
	2	hwse	6.75***	0.51**	-3.43***	0.77	46
	2	abcse	5.78***	0.48**	-3.32**	0.77	47
	2	hpse	3.99***	0.55**	-4.07**	0.68	47
	3	hwse	3.56***	0.48*	-3.22*	0.67	46
	3	abcse	3.71***	0.62**	-4.30**	0.66	46
	3	spse	6.00***	0.51*	-3.42*	0.66	46
	3	hpse	2.54***	0.72**	-5.17**	0.55	46
	4	hwse	3.62***	0.49*	-3.31*	0.66	43
	4	abcse	3.48***	0.54*	-3.69*	0.61	43
	4	spse	4.71***	1.00***	-6.99***	0.51	43
	4	hpse	2.38***	0.79**	-5.65**	0.50	43
	5	hwse	4.48***	0.90**	-6.43**	0.63	35
	5	abcse	3.97***	0.69*	-4.89*	0.52	35
	5	hpse	3.10***	0.81**	-5.94**	0.57	35
Grass	1	hpse	6.38***	0.95***	-7.15***	0.52	50
	2	abcse	6.82***	0.80***	-5.76***	0.72	50
	2	hpse	4.66***	0.88***	-6.63***	0.64	50
	3	hwse	4.34***	0.75**	-5.22**	0.65	49
	3	abcse	4.49***	0.91***	-6.51***	0.64	49
	3	spse	7.34***	0.78**	-5.51***	0.64	49
	3	hpse	3.03***	1.04***	-7.56***	0.53	49
	4	hwse	4.74***	0.70*	-4.91*	0.63	46
	4	abcse	4.55***	0.77*	-5.44*	0.58	46
	5	hwse	5.72***	1.28**	-9.29**	0.57	38
	5	hpse	3.90***	1.18**	-8.77**	0.51	38
Forb	2	hwse	16.0***	2.98***	-21.7***	0.67	32
	2	abcse	14.1***	2.73**	-20.1**	0.67	32
	2	hpse	9.14***	3.13***	-23.5***	0.58	32
	3	hwse	8.98***	2.54**	-18.3**	0.61	31
	3	abcse	9.28***	2.93**	-21.4**	0.53	28
	3	spse	15.2***	2.53**	-18.2**	0.62	31
	3	hpse	5.79**	3.38**	-24.8**	0.50	31
	5	hwse	12.3**	3.80**	-27.9**	0.51	24
Shrub	2	tse	1.67***	1.51**	-11.9**	0.53	47
	2	spse	22.5***	1.58**	-11.5**	0.53	47

The polynomial regression models that included squared values and crossproduct terms improved the R^2 values for the native and reclaimed areas. Table 3 lists some of the best polynomial models based on significance of parameters and resulting R^2 values (greater than 0.75). These values are generally higher than the multiple linear native models, although a few model R^2 values decreased.

Table 3. Selected polynomial regression models[1] for native areas.

Model[2]	R^2
$Comg_{hwse,1}$ = 4.35 - 13.28hwse - 11.44SO_4 - 0.52pH - 0.24EC - 0.27(SO_4*SO_4) + 1.58(SO_4*pH) + 0.23(SO_4*EC)	0.81
$Comg_{abcse,1}$ = 3.45 - 7.66abcse - 10.9SO_4 - 0.38pH + 16.1(abcse*SO_4) - 0.30(SO_4*SO_4) + 1.48(SO_4*pH)	0.84
$Comg_{hwse,4}$ = 2.90 - 29.0hwse + 0.08SO_4 - 0.37pH - 1.42(hwse*SO_4) + 4.70(hwse*pH)	0.88
$Comg_{abcse,4}$ = 1.66 - 18.6abcse + 0.31SO_4 - 0.21pH + 10.31(abcse*abcse) - 2.43(abcse*SO_4) + 2.85(abcse*pH)	0.86
$Comg_{hpse,4}$ = 56.6 - 22.9hpse + 0.32SO_4 - 15.1pH + 6.55(hpse*hpse) - 1.82(hpse*SO_4) + 3.29(hpse*pH) + 1.00(pH*pH)	0.81
$Grass_{hwse,1}$ = -1.36 + 290hwse - 11.8(SO_4) + 0.27pH - 0.22EC + 497(hwse*hwse) - 0.27(SO_4*SO_4) - 40.7(hwse*pH) + 1.63(SO_4*pH) + 0.23(SO_4*EC)	0.84
$Grass_{hwse,2}$ = 0.25 + 21.4hwse + 0.48SO_4 - 0.30EC - 24.9(hwse*hwse) - 0.46(SO_4*SO_4) + 0.26(SO_4*EC)	0.80
$Grass_{abcse,2}$ = 1.49 - 40.8abcse - 0.16pH - 6.27(abcse*pH)	0.86
$Grass_{hwse,4}$ = 4.22 - 45.77hwse + 0.03SO_4 - 0.54pH - 1.36(hwse*SO_4) + 7.06(hwse*pH)	0.87
$Grass_{abcse,4}$ = 3.01 - 33.3abcse + 0.09SO_4 - 0.39pH + 12.6(abcse*abcse) -2.58(abcse*SO_4) + 4.85(abcse*pH)	0.87
$Forb_{hwse,1}$ = 16.2 - 87.9hwse - 47.1SO_4 - 1.88pH - 0.31EC + 1186(hwse*hwse) - 0.63(SO_4*SO_4) + 5.95(SO_4*pH) + 1.13(SO_4*EC)	0.82
$Forb_{hwse,2}$ = 0.72 + 58.0hwse - 0.18SO_4 - 1.16EC - 62.1(hwse*hwse) - 1.60(SO_4*SO_4) + 1.18(SO_4*EC)	0.81
$Forb_{hwse,4}$ = 25.8 - 167hwse - 3.56pH+ 23.9(hwse*pH)	0.86
$Forb_{abcse,4}$ = 31.7 - 175abcse - 4.42pH + 25.2(abcse*pH)	0.81
$Shrub_{hwse,1}$ = 9.46 + -909hwse - 44.3(SO_4) + 13.8EC - 1.30pH - 1108(hwse*hwse) - 0.77(SO_4*SO_4) + 129(hwse*pH) + 6.30(SO_4*pH) - 1.90(pH*EC)	0.90
$Shrub_{abcse,1}$ = -4.98 + 2.94abcse - 39.4(SO_4) + 0.72pH + 12.7EC - 0.67(SO_4*SO_4) + 5.63(SO_4*pH) - 1.75(pH*EC)	0.80
$Shrub_{hpse,1}$ = -4.81 - 15.1hpse - 17.2SO_4 + 0.76pH + 0.03EC + 78.7(hpse*hpse) - 21.9(hpse*SO_4) + 2.56(SO_4*pH) + 0.69(SO_4*EC)	0.85
$Shrub_{hwse,2}$ = 0.05 + 10.9hwse + 0.67SO_4	0.86
$Shrub_{spse,2}$ = -10.8 + 74.5spse + 0.38SO_4 + 1.53pH + 8.44(spse*SO_4) - 11.4(spse*pH)	0.82

[1] Selection based on significance of parameters at p=0.05 combined with R^2 values.
[2] tse = total soil Se; hwse = hot water soluble soil Se; abcse = AB-DTPA extractable soil Se; spse = saturated paste soil Se; hpse = dihydrogen phosphate soil Se; EC = electrical conductivity; pH = soil pH; SO_4 = soil sulfates

To test the validity of the 1991 derived simple linear regression models, the 1992 data set was used to compare independently observed values with predicted values from the 1991 models. Those with resulting R^2 values greater than 0.40 are listed in Table 4. No validation was made using multiple linear regression models or polynomial models. Validation regressions were separately conducted by: type; type within soil extract; type within soil extract and lifeform category; and by type within soil extract, lifeform category and depth. The greatest number of significant slopes were found by type within soil extract and by type within soil extract and lifeform category. Significant slopes were found for all four soil extracts within the reclaimed area but R^2 values were generally low, i.e., 0.44-0.47.

Dividing the reclaimed areas into relative ages did improve the R^2 values of the reclaimed area polynomial regressions (Table 5). However, the overall R^2 values remain low.

Table 4. Validation of simple regression models with 1992 data.

Type[1]	Soil Se[2]	Lifeform Category	Depth	Intercept	Slope[3]	Degrees of Freedom	R-Squared
			By Type				
2	-	-	-	0.61	2.00**	326	0.41
			By Type within Soil Extract				
2	hwse	-	-	-0.27	3.04***	80	0.45
2	abcse	-	-	-0.37	3.05***	80	0.47
2	spse	-	-	0.47	1.57***	80	0.44
2	hpse	-	-	0.74	1.99***	80	0.45
			By Type within Soil Extract, Lifeform Category and Depth				
1	hwse	Forb	4	1.10*	1.56*	7	0.56
1	hwse	Shrub	4	29.5*	-34.8*	6	0.60
1	abcse	Forb	5	-2.85	4.86	5	0.40
1	spse	Forb	4	-0.69	1.58**	7	0.72
1	spse	Forb	5	-34.8*	18.2*	5	0.60

[1] 1 = Native; 2 = Reclaimed

[2] hwse = hot water soluble Se; abcse = AB-DTPA extractable Se; spse = saturated paste Se; hpse = dihydrogen phosphate extractable Se

[3] Slope from regressing the observed plant Se levels on the predicted plant Se levels; denotes significance (or lack thereof) from 0.0; the second indicates the level of significance from 1.0. Level of significance: * p=0.05, ** p=0.01, *** p=0.001

Discussion

Total soil Se in native areas, regardless of mine, averaged 1.06 ppm. Extractable Se (ppm) in native areas regardless of mine for hwse, abcse, spse, and hpse was 0.08, 0.10, 0.06, and 0.19, respectively. Reclaimed area means were generally higher than native area means. Total soil Se in reclaimed areas, regardless of mine, averaged 1.11 ppm. Extractable Se (ppm) in reclaimed areas, regardless of mine, for hwse, abcse, spse, and hpse was 0.17, 0.13, 0.05, and 0.21, respectively.

Total plant Se was generally higher in native areas, and Mine S values higher than Mine L. The highest plant Se values were found in the lifeform categories forb and shrub. Composite grass and grass Se values were within a similar range, as would be expected. Grasses generally ranged from: 0.25-0.86 ppm in Mine L native; 0.01-4.08 ppm in Mine L reclaimed; 0.31-4.88 ppm in Mine S native; and 0.05-4.32 ppm in Mine S reclaimed. The highest forb values were found in Mine S native; the highest shrub values were found in Mine L reclaimed.

Results of the 1991 sampling program indicate some possible relationships between various measured independent variables including soil extractable Se and plant Se levels. It is evident from the modeling process that data between the two mines could be combined by type but that data between types could not be combined, as well as not being combined by depth within the native areas or between depth 1 reclaimed (i.e., replaced topsoil) and depths 2 and 3 (i.e., backfill material).

Table 5. Summary of polynomial regression models[1] by age of the reclaimed area.

Soil or Backfill[2]	Plant lifeform	Soil Se	R^2			
			Linear	Quad.[3]	Cross[4]	Total
		Reclaimed Areas Seeded between 1986 and 1991				
Topsoil	Comg	abcse	0.37	0.19	0.06	0.62
	Comg	spse	0.33	0.31	0.13	0.76
	Shrub	tse	0.63	0.08	0.22	0.93
	Shrub	abcse	0.09	0.09	0.43	0.62
	Shrub	hpse	0.11	0.24	0.44	0.79
Backfill	Grass	abcse	0.35	0.22	0.07	0.64
	Shrub	tse	0.28	0.23	0.09	0.61
	Shrub	hwse	0.19	0.29	0.12	0.60
	Shrub	abcse	0.31	0.23	0.12	0.65
	Shrub	hpse	0.29	0.25	0.08	0.63
		Reclaimed Areas Seeded between 1979 and 1985				
Topsoil	Comg	tse	0.26	0.21	0.15	0.62
	Comg	hwse	0.19	0.22	0.32	0.73
	Comg	abcse	0.15	0.33	0.30	0.77
	Comg	spse	0.17	0.33	0.10	0.60
	Comg	hpse	0.15	0.30	0.42	0.87
	Grass	hwse	0.08	0.29	0.37	0.74
	Grass	spse	0.10	0.38	0.13	0.61
	Grass	hpse	0.12	0.28	0.45	0.85
	Forb	tse	0.08	0.56	0.28	0.92
	Forb	hwse	0.09	0.49	0.16	0.74
	Forb	abcse	0.09	0.45	0.06	0.61
	Forb	spse	0.12	0.21	0.30	0.64
	Forb	hpse	0.09	0.46	0.27	0.82
Backfill	Comg	hwse	0.36	0.17	0.10	0.63
	Comg	abcse	0.42	0.14	0.11	0.67
	Comg	spse	0.35	0.22	0.04	0.62
	Comg	hpse	0.28	0.25	0.07	0.61

[1] Contribution of each division of the model to the total R^2.
[2] Replaced topsoil (approx. 60 cm); Regraded backfill material (0-120cm)
[3] Quadratic Model
[4] Cross Product Model

The multiple linear model of soil Se and pH provided the highest R^2 values. However, the variability found within the reclaimed areas, as a collective group, provided reasonable R^2 values only within the polynomial models. The list of possible polynomial models exemplifies the extreme complexity of predicting plant level Se. It is evident that soil Se alone may not be enough information to predict the process of plant Se uptake. Age of the reclaimed area, i.e., when it was seeded relative to the sampling date, may be an important variable that should be included in future analysis.

The validation of the 1991 models with the 1992 vegetation data resulted in relatively high R^2 in very few of the simple models, i.e., 0.72 in spse by type within soil extract, lifeform category and depth. The vast majority of resulting R^2 values indicate that the 1991 models, derived from 1991 soil and vegetation information, are poor predictors of the 1992 plant Se levels, specifically for the native areas. Using the polynomial models, R^2 values were improved for the reclaimed areas when sites were separated by age groups.

No clear relationship between soil Se and plant Se was found on reclaimed areas. Soil Se at depths 2 and 3 for native areas appeared to be the most significant depths for predicting plant Se levels. This may be due to the presence of the calcium carbonate layer at 30-90 cm indicating the lower level of leaching within the soil profile. Since Se can weather and become mobile in the profile and available for plant uptake, increased Se levels are likely present at this depth if sources in the profile are present.

The extractable procedures for abcse and hwse produced generally equal results. Phosphate extractable Se was generally higher than other Se extractable levels because of the release of soluble and exchangeable Se from the soil and backfill materials. Saturated paste Se levels were generally low and inconsistent resulting in few statistically relevant relationships between soil and plant Se.

The weather during the 1992 field season was entirely different from the 1991 season. The 1991 season was cool and wet in May and warm in July; the 1992 field season was warm and dry in May and cool and wet in June and July. This may have confounded the statistical relationship for the 1992 validation.

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