5.0 RESULTS AND DISCUSSION

5.1 Background

Soils are the primary source of trace elements for plants and through feed and food crops, for animals and humans. Trace element problems (deficiencies or toxicities) are therefore generally associated with soil properties on a regional or local basis.

The availability of trace elements to plants is influenced by both parent material and soil development, but soil properties can operate very differently for different trace elements. For example, high concentrations of Mo are found only in plants growing on poorly drained soils, whereas poorly drained or poorly aerated soils tend to produce plants with low Se concentration. The trace element requirements and tolerances of plants differ from those of animals and humans, to the extent that, deficiencies or toxicities in plants do not necessarily translate into deficiencies or toxicities in animals or humans. For example:

1. Higher plants can produce optimum growth and have Se and I concentrations that are deficient for animals and humans.
2. Some plants growing on high Se soils can accumulate Se concentrations that are toxic to grazing animals.
3. B toxicity in plants is common in some arid regions of the world but B toxicity is rare in animals or humans.
4. The trace elements I, F, Se, Co, As, Li, Cr, Si, Sn, and V are considered essential for animals and humans but not for plants.

5.2 Identifying Deficiencies and Toxicities

Various approaches have been used for identifying and mapping trace element problems. Early attempts (in the 1940's and 1950's in the USA) consisted mainly of literature reviews and personal communication among soil scientists, agronomists, and animal nutritionists. This led to mapping of data from plant and feed analysis laboratories. In some cases, geographical and soil association maps were used to select sampling sites for specific crops and to identify areas where deficiencies or imbalances in trace elements were suspected. In Alberta, general areas of Se deficiency have been delineated from analysis of forage samples. Se levels in forage samples analysed from 1970 to 1991 have been mapped by legal location (Corbett, 2004).

Mapping of trace element problems from data generated by routine soil analysis for fertility managements has been limited in that:

1. Trace elements are not often analysed in routine soil testing;
2. For many of the trace elements, deficiency and toxicity criteria are not well defined.

As was identified in the report on, "The Cu, Fe, Mn, and Zn Status of the ASEA Soil Quality Benchmark Sites", composite samples of fields taken for routine soil analysis can mask variation that occurs within fields. At some sites, Cu and Zn levels ranged from deficient to highly adequate within the three slope positions sampled along a catena.

5.3 Boron (B)

B is essential to plants and is taken up as H_3BO_3 (boric acid). There is increasing evidence that it may be required for normal mineral metabolism in mammals (Welch et al., 1991). B deficiency does not follow well-defined geographic patterns related to soils. Deficiencies are widespread throughout the world and typically occur on well-drained light textured soils that are low in soil organic matter (SOM).

Crops vary widely in their susceptibility to B deficiency. Monocotyledons generally have lower B requirements than dicotyledons. Crops with high B requirements include alfalfa, beets, turnips, canola and apples. B deficiency may occur when plant B content is < 15 mg/kg on a dry matter basis but critical values ranging from 5 to 30 mg/kg have been reported.

Toxicity can occur when the B content of plants exceeds 200 mg/kg although there are reports of corn tolerating in excess of 1000 mg/kg and barley seedlings being impaired at 80 mg/kg. B toxicity in plants is fairly common in semiarid regions with alkaline soil but B toxicity has seldom been reported in Canada. B toxicity in animals is primarily an experimental phenomenon but Underwood (1977) reported B toxicity in lambs grazing high-B plants growing on solonetz and solonchak soils in Russia.

Agronomists in Alberta have occasionally reported seeing B deficiency symptoms on alfalfa and canola, but documented responses to B fertilization are rare. Nyborg and Hoyt (1970) obtained response to B fertilization of turnip rape in greenhouse studies with Grey Luvisols in the Peace River region. Poor seed set of turnip rape on some Grey Luvisols in the region was attributed to B deficiency. B deficiency symptoms on alfalfa and response to B fertilization were observed on a light textured Luvisol in the Barrhead area (Dowbenko, R., personal communication).

5.3.1 Boron Results from Benchmark Sites

The hot water extractable B for the 129 sampling locations (43 sites x 3 slope positions) in this study:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.92	0.29	2.32	0.4	43
15-30	0.91	0.12	3.22	0.53	48

Sixteen percent of the samples were in the marginal to deficient range (≤ 0.5 mg/kg) and there were no samples in the toxic range (> 5 mg/kg). Various extension bulletins have indicated there may be potential toxicity to plants at soil B levels of 3 to 5 mg/kg (Marx et al, 1996; Rehm et al., 1993). However, critical levels of B are difficult to establish as plants differ in the amount of B they require.

Effect of Soil Properties

As indicated earlier, B deficiency does not tend to follow well-defined geographic patterns although deficiencies tend to occur on low organic matter, light textured soils. In this study, low B values tended to occur on light textured soils but some low values also occurred on loam and clay loam soils. Hot water extractable B (HWEB) was significantly correlated with OC (r = 0.53) [Table 1]. The mean OC content of samples in the marginal to deficient range was low (1.6 %).

Effect of Ecoregion

The mean HWEB was highest in Ecoregions PL, AP and FG and lowest in Ecoregions MM and MG (Table 2). B was significantly lower in Ecoregions MM and MG, than in the other ecoregions. However, the frequency of low and marginal B values (≤ 0.5 mg/kg) in the MM and MG Ecoregions was low compared to the other ecoregions. This is because standard deviations (SD) were lower in these two ecoregions than in other ecoregion (SD = 0.18 and 0.13 in MM and MG respectively, compared to 0.3 to 0.4 in the other ecoregions for the 0-15 cm depth). The BT Ecoregion had the highest frequency of marginal or deficient values (5 of 8 sites; sites 680, 681, 684, 687 and 703). The MG Ecoregion had the lowest mean B content (0.73 mg/kg) but only one of the eight sites had marginal B values. The SD in the MG Ecoregion was low (Table 3).

Table 1. Correlation coefficients where r>0.5.

	B	Cl	Mo	Ni	Co	Si	Cr	Cd	Se	Sand	Silt	Clay	CEC	$CaCO_3$	OC	P	K	pHw	pHc
B	1.0														0.53				
Cl		1.0																	
Mo			1.0															0.72	0.62
Ni				1.0	0.55			0.69					0.63		0.46				
Co				0.55	1.0													0.55	
Si						1.0													
Cr							1.0												
Cd				0.69				1.0											
Se									1.0				0.54		0.55				
Sand										1.0									
Silt											1.0								
Clay												1.0							
CEC				0.63					0.54				1.0						
$CaCO_3$														1.0					
OC	0.53			0.46					0.55						1.0				
P																1.0			
K																	1.0		
pHw			0.72		0.55													1.0	
pHc			0.62																1.0

Table 2. Mean micronutrient and trace element values for seven ecoregions.

Ecoregion	No. of Sites	B[1] (mg/kg)	Cl[2] (mg/kg)	Mo[1] (mg/kg)	Ni[3] (mg/kg)	Co[3] (mg/kg)	Si[1] (mg/kg)	Cr[3] (mg/kg)	Cd[3] (mg/kg)	Se[4] (mg/kg)
					0-15 cm					
PL	10	1.05ab[#]	11.5	0.020ab	2.23	0.163	167	0.008	0.173ab	0.650
BT	8	0.79b	9.6	0.013b	1.99	0.242	117	0.010	0.125b	0.396
MB	1	1.54	10.1	0.067	1.27	0.171	234	0.009	0.234	0.500
AP	9	1.00ab	12.7	0.022ab	2.33	0.272	120	0.011	0.177ab	0.493
MM	5	0.76b	5.5	0.025ab	1.78	0.255	127	0.011	0.194ab	0.427
FG	2	1.36a	13.0	0.018ab	2.96	0.214	149	0.008	0.278a	0.483
MG	8	0.73b	9.0	0.051a	1.42	0.131	131	0.009	0.103b	0.346
					15-30 cm					
PL	10	1.22	9.9	0.029	1.97	0.091	429	0.008	0.086b	0.690
BT	8	0.75	7.3	0.011	1.37	0.102	141	0.008	0.051b	0.388
MB	1	1.36	6.2	0.056	1.04	0.094	215	0.009	0.152	0.500
AP	9	0.95	8.8	0.025	1.98	0.132	73	0.009	0.104b	0.441
MM	5	0.67	4.8	0.022	1.51	0.139	156	0.009	0.125b	0.433
FG	2	1.20	11.6	0.023	2.57	0.170	120	0.008	0.204a	0.500
MG	8	0.66	7.6	0.053	1.42	0.102	120	0.008	0.075b	0.342

[1] Hot water extractable
[2] 0.01 M $Ca(NO_3)_2$ extractable
[3] DTPA extractable
[4] Total
[#] means followed by different letters are significantly different at P < 0.05 based on SNK means separation test

Table 3. Average standard deviation of micronutrient and trace element values for seven ecoregions.

Ecoregion	No. of Sites	B[1] (mg/kg)	Cl[2] (mg/kg)	Mo[1] (mg/kg)	Ni[3] (mg/kg)	Co[3] (mg/kg)	Si[1] (mg/kg)	Cr[3] (mg/kg)	Cd[3] (mg/kg)	Se[4] (mg/kg)
					0-15 cm					
PL	10	0.40	6.81	0.02	1.12	0.11	133	0.001	0.12	0.37
BT	8	0.31	5.2	0.013	1.40	0.152	93	0.003	0.113	0.253
MB[*]	1	.	.	.	.	.	.	.	.	.
AP	9	0.43	13.2	0.019	0.87	0.149	87	0.002	0.059	0.159
MM	5	0.18	4.3	0.020	0.67	0.212	53	0.003	0.091	0.364
FG	2	0.38	13.2	0.006	1.93	0.140	66	0.0005	0.064	0.024
MG	8	0.13	6.3	0.032	0.43	0.050	80	0.003	0.052	0.096
					15-30 cm					
PL	10	0.75	6.14	0.05	1.48	0.07	570	0.002	0.10	0.47
BT	8	0.33	4.9	0.008	0.85	0.058	159	0.002	0.033	0.326
MB[*]	1	.	.	.	.	.	.	.	.	.
AP	9	0.57	7.3	0.022	1.03	0.084	39	0.003	0.051	0.169
MM	5	0.23	3.4	0.014	0.63	0.094	125	0.002	0.071	0.374
FG	2	0.20	8.0	0.011	1.86	0.108	55	0.001	0.071	0.094
MG	8	0.15	7.3	0.034	0.40	0.031	96	0.001	0.032	0.097

[1] Hot water extractable
[2] 0.01 M $Ca(NO_3)_2$ extractable
[3] DTPA extractable
[4] Total
[*] MB excluded from statistical analysis because it contains only 1 site

Effect of Slope Position

The mean HWEB concentrations were significantly lower in the upper and mid slope positions than on the lower slope positions in the 0 -15 cm depth, but there was no significant difference among slope positions for the 15-30 cm depth (Table 4). The higher B levels in the lower slope positions were generally associated with higher levels of OC. Also, B in soil solution occurs as relatively mobile anions and can therefore move laterally with soil water into lower slope positions.

Effect of Management

To the extent that tillage and cropping practices influence SOM, management could influence B availability. There was no indication in the management information, that B fertilizer was applied at any of the sites.

Table 4. Effect of slope position on selected micronutrients and trace elements from 43 benchmarks.

Slope Position	Sample Depth (cm)	B[1] (mg/kg)	Cl[2] (mg/kg)	Mo[1] (mg/kg)	Ni[3] (mg/kg)	Co[3] (mg/kg)	Si[1] (mg/kg)	Cr[3] (mg/kg)	Cd[3] (mg/kg)	Se[4] (mg/kg)
U	0-15	0.94b*	9.7	0.033	1.73b	0.171b	120b	0.009	0.150b	0.42b
M	0-15	1.02b	9.8	0.028	1.86b	0.193b	176a	0.010	0.17b	0.47ab
L	0-15	1.15a	11.2	0.031	2.4a	0.257a	152ab	0.009	0.231a	0.52a
U	15-30	0.92	8.5	0.031	1.46b	0.1b	182	0.009	0.085b	0.48
M	15-30	0.94	7.1	0.033	1.65ab	0.104b	189	0.009	0.1b	0.45
L	15-30	1.05	8.5	0.029	1.98a	0.152a	167	0.008	0.157a	0.49

[1] Hot water extractable
[2] 0.01 M $Ca(NO_3)_2$ extractable
[3] DTPA extractable
[4] Total
* For each sample depth, means followed by a different letter are significantly different at $P<0.05$ based on SNK means separation

5.4 Chlorine (Cl)

Cl has been recognized as an essential plant nutrient for many years (Romheld and Marschner, 1991), but since it is abundant in the environment (both lithosphere and atmosphere), deficiencies in the field were generally thought to be rare. However, more recent work by Christensen et al. (1981), Fixen et al. (1986), and others has found prophylactic and beneficial properties of the element. Low rainfall, little or no need for K fertilizer (KCl), and the large land locked geography of the Northern Great Plains region have been cited as reasons for relatively frequent reports of response to Cl fertilization. (Note: land locked regions receive low levels of Cl in precipitation compared to coastal regions).

Plants utilize chlorine as the Cl^- anion. In soils, common Cl salts are highly soluble and Cl^- is highly mobile. Less than 45 kg/ha Cl in the 0-60 cm depth (approx. 12 mg/kg in the 0-15 cm depth) has been reported to be deficient in the Northern Great Plains region (Fixen et al., 1986). Crop response to Cl in the Northern Great Plains Region appears to result from prophylactic or beneficial effects rather than its function as an essential plant nutrient.

5.4.1 Chlorine Results from Benchmark Sites

The 0.01 M $Ca(NO_3)_2$ extractable Cl^- for the 129 sampling locations:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	10.3	2.2	74.7	8.8	85.4
15-30	8.2	1.2	32.0	6.5	79.3

Forty one percent of the samples were below the critical level of 12 mg/kg (0-30 cm) and none of the samples were in the toxic range.

Effect of Soil Properties

Chloride levels in this study were not significantly correlated with soil properties nor the other elements assessed in this report (Table 1).

Effect of Ecoregion

The MM Ecoregion had the lowest Cl levels but there were no significant differences among ecoregions (Table 2). The MM Ecoregion was the only one with a mean Cl level below the critical levels of 12 mg/kg. The percentage of sampling locations with Cl levels below the critical level ranged from 17 % in the PL ecoregion to 73 % in the MM Ecoregion.

Effect of Slope Position

There were no significant differences in Cl levels among slope positions (Table 4). Low Cl values were more strongly associated with sites than with slope position or ecoregion. Sites 681, 688, 730, 739, 743, 746, 769, 786, 791, 793, 804, 815 and 2828 had Cl values below the critical level in all three-slope positions. At 14 of the 43 sites (33 %), the mean Cl level of the three slope positions was below the critical level. Overall, 53 of the 129 sampling locations (41 %) were below the critical level.

Effect of Management

Management practices that include the use of fertilizers containing KCl or manure could significantly increase soil Cl levels.

5.5 Molybdenum (Mo)

Mo is an essential element for both plants and animals. In plants, it is taken up as MoO_4^{2-} and is involved in NO_3 reduction, protein synthesis and biological N_2 fixation. In animals, both deficiencies and toxicities have been reported. Excess Mo causes diarrhea of cattle (teart scours) in England. In the Inter-lakes Region of Manitoba, high Mo in association with low Cu has been reported to cause Mo toxicity (molybdenosis) in cattle (Corbett, R., personal communication). More recent work has indicated that Mo supplementation in human diets may have anticarcinogenic benefits (Miller et al., 1991).

Mo in soils has not been extensively researched, in large part because deficiencies are rare. Mo availability to plants is strongly affected by soil pH. Availability increases as pH increases. Therefore, Mo deficiency in acid soils is often corrected by liming.

Acid ammonium oxalate (AAO) is the soil test extractant most commonly used for Mo (Sims and Johnson, 1991). A level of >0.2 mg/kg AAO extractable Mo has been indicated as adequate. However, Johnson and Fixen (1990) state that, "Critical levels of extractable available Mo remain unknown for lack of suitable extraction reagent or Mo deficient soil. Identifying critical levels is made more difficult by the fact that plant response in marginally deficient soils appears to be more influenced by liming than by application of Mo". Critical levels for hot water or DTPA extractable Mo, used in this study, have not been established.

5.5.1 Molybdenum Results from the Benchmark Sites

The hot water extractable Mo for the 129 sampling locations:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.026	0.004	0.153	0.029	112
15-30	0.029	0.004	0.374	0.041	141

The extractable Mo value of 0.004 was the detection limit and occurred quite frequently. Values above 0.100 occurred infrequently. The high values did not occur on sandy soils with low Cu, which would indicate a potential for Mo toxicity in grazing cattle or sheep (molybdenosis). (Note regarding the high CV: It may be useful to examine plant tissue levels at some sites to determine if toxicities or deficiencies could occur.)

Effect of Soil Properties

Extractable Mo was significantly correlated with soil pH_w ($r = 0.72$) and pH_c ($r = 0.62$), but not with other soil properties, or with the other elements examined in this study (Table 1).

Effect of Ecoregion

The mean extractable Mo in the 0-15 cm depth ranged from 0.013 mg/kg in the BT Ecoregion to 0.051 mg/kg in the MG Ecoregion but there were no significant differences among other ecoregions (Table 2).

Effect of Slope Position

Differences in extractable Mo among slope positions were small and not significant (Table 4).

Effect of Management

There was no indication of management effects on extractable Mo, although liming could increase Mo availability on acid soils.

5.6 Nickel (Ni)

The main interest in Ni has concerned its toxic effects on plant, but more recent research has indicated Ni requirements for both plants and animals. Asher (1991) discusses the role of Ni in a chapter in “Micronutrients in Agriculture”, entitled “Beneficial Elements, Functional Nutrients and Possible New Essential Elements”. Depending on the reference, Ni is considered as either a functional or essential nutrient. Havlin et al. (1999) stated that Ni is the latest nutrient to be established as essential for plants. It is taken up by plants as Ni^{2+} and has been shown to be required for urea reduction (Dixon et al., 1975) and for grain viability of barley (Brown et al., 1987).

Critical soil levels for Ni deficiency were not identified. However, Asher (1991) lists toxic levels (DTPA extractable) for various grasses ranging from 6 mg/kg for Bermuda grass (Cynodon dactylon) to 112 mg/kg for pangola grass (Digitaria decumbens). Toxic symptoms have been described as being similar to Fe deficiency. In cereals and grasses, variation in chlorosis along the length of the leaf gives a characteristic transverse banding effect. Risser and Baker (1990) state that, "most background levels in soils and plants are of little concern for human health, since inhibition of plant growth and development by excess Ni places a limit on Ni entering the food chain".

5.6.1 Nickel Results from the Benchmark Sites

The DTPA extractable Ni for the 129 sampling locations:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	2.01	0.51	5.87	1.11	55.22
15-30	0.029	0.004	0.374	0.041	141.38

If 6 mg/kg is used as the critical toxic level (reported as the toxic level for Bermuda grass -a sensitive species) none of the values fall in the toxic range. A critical deficient value could not be identified.

Effect of Soil Properties

Ni was significantly correlated with the soil properties CEC ($r = 0.63$) and OC ($r = 0.46$), and with Co ($r = 0.55$) and Cd ($r = 0.69$) (Table 1).

Effect of Ecoregion

There were no significant differences in DTPA extractable Ni levels among ecoregions (Table 2). Values ranged from 1.42 in the MG ecoregion to 2.96 in the FG ecoregion.

Effect of Slope Position

Extractable Ni was significantly higher in the lower slope positions than in the mid or upper slopes (Table 4). This is likely related to higher levels of SOM in the lower slopes.

Effect of Management

Management practises that increase SOM could increase extractable Ni.

5.7 Cobalt (Co)

Cobalt was established as an essential nutrient for animals in the late 1930's and for plants in 1960 (Asher, 1991). Co is essential for ruminant animals. Rumen microflora require Co for synthesis of vitamin B_{12}. Co deficiency in ruminants is usually corrected by using Co fortified salt licks, adding it to drinking water, or by using Co boluses. Co fortified salt is commonly used in Alberta, although there are no reports of Co deficiency (Corbett, R., personal communication).

In plants, Co is essential for N_2 fixation by leguminous plants. Co has not been shown to be essential for plants, which are not dependent on N2 fixation, but beneficial effects have been reported for several crops. Plants take it up as Co^{2+}.

Total Co content of soils typically ranges from 1 to 10 ppm and average about 8 ppm. Forages produced on soils containing < 5 ppm of total Co often results in Co deficiency in ruminants. Soils prone to Co deficiency include (1) acidic, highly leached sandy soils; (2) some calcareous soils; and (3) some peaty soils (Havlin et al., 1999). A critical deficiency level for DTPA extractable Co was not identified.

5.7.1 Cobalt Results from Benchmark Sites

The DTPA extractable Co for the 129 sampling locations:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.208	0.034	0.847	0.151	72.6
15-30	0.113	0.019	0.419	0.075	33.4

<u>Effect of Soil Properties</u>

Co was significantly correlated with pHw (r = 0.55) and Ni (r = 0.55) (Table 1).

<u>Effect of Ecoregion</u>

There were no significant differences in DTPA extractable Co among ecoregions (Table 2).

<u>Effects of Slope Position</u>

Extractable Co was significantly higher in the lower slope positions than the upper and mid slope positions in both the 0-15 cm and 15-30 cm samples (Table 4).

<u>Effects of Management</u>

There were no apparent effects of management on extractable Co.

5.8 Silicon (Si)

Welch et al. (1991) stated "since 1970, eleven additional trace elements have been proposed to be required by animals and possibly humans". They include As, B, Br, Cd, F, Pb, Li, Ni, **Si**, Sn and V. Except for Ni and B, none are considered to be essential for higher plants. Si is regarded as an essential trace element for normal growth and development in animals, where it is involved in the formation of bone and cartilage.

While an essential role for silicon in plants has not been established, many beneficial effects have been reported. Si is absorbed by plants as silicic acid (H_4SiO_4). Cereals and grass typically contain 0.2 to 2 % Si on a dry weight basis. Accumulator plants such as horsetail can accumulate up to 20 % Si (DW). Rice is often supplemented with Si when the Si content in the straw falls below 11 %.

Si impregnates walls of epidermal and vascular tissue. Reported beneficial effects include: correction of soil toxicities of Mn, Fe and Al, disease resistance, greater stalk strength and lodging resistance, increased P availability and reduced transpiration (drought resistance).

Si is the second most abundant element in the earths' crust, averaging 28 %. Soils range between 28 % and 35 %. The main Si species in soil solution is silicic acid (H_4SiO_4). Levels of 3 ppm to 37 ppm Si in solution have been reported for normal soils. Less than 0.9 to 2 ppm in soil solution is considered deficient for sugarcane. An adequate level for rice is considered to be >100 ppm (Havlin et al., 1999).

5.8.1 Silicon Results from the Benchmark Sites

Hot water extractable Si values for the 129 sampling locations:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	137	12	858	109	79.6
15-30	192	15	1970	322	167.7

(Note: values over 1000 mg/kg occurred at 3 sites in the PL ecoregion)

<u>Effect of Soil Properties</u>

Si was not significantly correlated with soil properties, nor the other elements discussed in this report (Table 1).

<u>Effect of Ecoregion</u>

There were no significant differences in hot water extractable Si among ecoregions (Table 2).

<u>Effect of Slope Position</u>

Extractable Si in the 0-15 cm samples was significantly higher in the mid slope than in the upper slope position. There were no significant differences among slope positions in the 15-30 cm samples (Table 4).

<u>Effect of Management</u>

There were no apparent effects of management on extractable Si. Cereal straw contains relatively large amounts of Si. Straw removal could contribute to reduced soil Si levels in the long term.

5.9 Chromium (Cr)

The metals generally considered as toxic include: Cd, **Cr**, Hg, Ni, and Pb. Cr and Ni are the most phytotoxic. These metals are economically important and used in substantial quantities, thus providing the possibility of soil and plant contamination from anthropogenic sources such as mining and waste disposal. Toxic metals are also added to soils in organic forms. The leather tanning industry is a large source of high Cr organic waste. Toxic levels can also occur naturally in soils developed on serpentine high in Cr and Ni.

Cr is toxic to plants in its common oxidation states, Cr(III) and Cr(VI). The Cr(III) cation is normally the form found in plants and is essential in human nutrition (Risser and Baker, 1990). Cr(VI) is an anion, which is mobile in soil and water and is toxic to aquatic life, microorganisms and animals. Hexavalent Cr is also a suspected human carcinogen (e.g. the movie "Erin Brokovich").

Good relationships between chelate soil test (e.g. DTPA) and plant uptake of Cr have not been established. Reasons cited include the mineral stability and slow kinetics of Cr dissolution (Risser and Baker, 1990). Test methods used for Cr include soluble Cr(VI), organic forms and total Cr.

In animals and humans, Cr is an essential trace element required for glucose, lipid and protein metabolism. Its predominant physiological role appears to be to improve the action of insulin. In results presented at 2003 Experimental Biology Conference (Campbell et al., 2003), research suggested that low intake of Cr may be linked to insulin resistance, a condition affecting one in three Americans and associated with obesity, type 2 diabetes and cardiovascular disease. The study suggested that US diets are inadequate in Cr. Research on cattle at the University of Guelph in Ontario by Mowat and Mallard (1993) has shown Cr supplementation during the first 21 – 29 days in feedlots improved weight gain and reduced morbidity or sickness due to bovine respiratory disease complex (also known as shipping fever).

5.9.1 Chromium Results from the Benchmark Sites

DTPA extractable Cr values for the 129 sampling locations were:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.010	0.005	0.027	0.003	30
15-30	0.008	0.004	0.017	0.002	25

Effect of Soil Properties

Cr was not significantly correlated with soil properties nor the other elements discussed in this report (Table 1).

Effect of Ecoregion

There were no significant differences in DTPA extractable Cr among ecoregions (Table 2). The total range in extractable Cr was small.

Effect of Slope Position

There were no significant differences in extractable Cr among slope positions (Table 4).

Effect of Management

There was no indication of industrial or municipal waste application at any of the benchmark sites. Therefore, toxic levels of Cr are not a concern.

5.10 Cadmium (Cd)

As referred to earlier (Welch et al., 1991), As, B, Br, **Cd**, F, Pb, Li, Ni, Sn, and V have been proposed as being required by animals and possibly humans. Beneficial effects, such as suppression of powdery mildew in crop, have also been reported for Cd. However, the main interest in Cd has been toxic concentrations in food and feed resulting from application of sewage sludge and phosphate fertilizers high in Cd.

Reports of Cd uptake by crops are highly variable, depending on crop type and soil conditions. Most field crops do not absorb appreciable quantities of Cd, but leafy vegetables such as spinach and swiss chard are known to accumulate Cd. One of the earliest reports of Cd toxicity in people was traced to the flooding of rice with water that drained from a mine (Welch et al., 1991). The concentration of Cd in corn forage was not affected by Zn fertilizer, containing from 1 to 2165 mg Cd kg^{-1} (Mortvedt, 1991).

Soil pH is a dominant factor affecting Cd availability. Availability increases as pH decreases. Sludge application is usually restricted to soils of pH 6.5 or above and rates are generally based on CEC.

Although some significant correlation of Cd uptake with DTPA extractable Cd have been reported, no critical values were given. Limitations for Cd application to soils are generally based on maximum accumulative loading. Maximum loading limits range from 2.5 to 5.0 lb Cd ac^{-1} based on soil texture (Risser and Baker, 1990). For fertilizers, risk based concentrations have been established. For diammonium phosphate, the safe level is 736 ppm (The Fertilizer Institute, 2000). Reported levels of Cd in diammonium phosphate in the U.S.A. show levels no higher than 200 ppm.

5.10.1 Cadmium Results from the Benchmark Sites

DTPA extractable Cd values for the 129 sampling locations were:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.161	0.026	0.660	0.108	67.1
15-30	0.093	0.004	0.634	0.087	93.6

<u>Effect of Soil Properties</u>

DTPA extractable Cd was not correlated with any of the soil properties, but was significantly correlated with Ni (r = 0.69) (Table 1).

<u>Effect of Ecoregion</u>

In the 0-15 cm depth, extractable Cd was significantly higher in the FG Ecoregion than in the MG, BT and PL Ecoregions. In the 15-30 cm depth, Cd was higher in the FG ecoregion than in all the other ecoregions. However, the highest Cd values occurred on sites PL 591 and 592, MB 615, BT 684, and MM 791 (Table 2). SD was high in the PL, BT and MM Ecoregions (Table 3).

<u>Effect of Slope Position</u>

Extractable Cd was higher in the lower slope position than in the upper and mid slope positions in both the 0-15 cm and 15-30 cm depths.

<u>Effect of Management</u>

There was no indication of industrial or municipal waste application at any of the benchmark sites. Therefore, toxic levels of Cd are not a concern.

5.11 Selenium (Se)

In the early 1930's, high concentrations of Se were identified as being responsible for animal production problems in parts of the western USA. The location of high Se areas was facilitated by collection and analysis of Se accumulator plants. The high Se soils were generally developed on shales of the Cretaceous or Permian geologic age. Crop plants and range grasses containing > 4 to 5 mg Se kg^{-1} (potentially detrimental) were generally confined to parts of fields or farms. High levels of Se in irrigation drainage water are also a concern in some areas (e.g. The Kesterson Wildlife Refuge in California).

Small areas of Se toxic soils have also been identified in Alberta, Saskatchewan and Manitoba (Fleming, 1980). Livestock deaths from Se toxicity are rare in Alberta, but have been reported in the Cypress Hills and Crowsnest Pass areas (Corbett, R., personal communication).

Se accumulator plants, such as *Astragalus* (milk vetch), the *Xylorhiz*a section of *Machaeranthera* (woody aster), *Haplopappus* (goldenweed) and some *Stanleya* (Prince's plume) can contain >50 mg Se kg^{-1}. Secondary Se absorbers include *Aster, Atriplex*, and *Grindelia* (Fleming, 1980).

While high levels of Se in plants dominate the literature, beneficial effects to symbiotic N fixation have been reported (Munson and Nelson, 1990).

The total Se concentration in most soils ranges between 0.1 and 2 ppm and averages about 0.3 ppm (Havlin et al., 1999). The forms include: selenides (Se^{2-}), elemental Se^{o}, selenites (Se^{4+}) and selenates (Se^{6+}). Selenates are highly soluble and the main species taken up by plants. Selenites are absorbed but to a lesser extent than selenates. Organic Se can also be an important fraction, since up to 40 % of the total Se in some soils is present in humus (Havlin et al., 1999). Se deficient soils generally occur on parent material developed from igneous rock.

For mobile elements such as Se, sampling depth is important. Soltanpour et al. (1982) found that soil samples from the 0-30 cm depth were useless for predicting Se content of wheat grain but Se in the 0-90 cm depth correlated well with Se in grain.

Se deficiency, expressed as white muscle disease in livestock, is quite prevalent in Alberta. Deficiencies are generally more prevalent in the higher rainfall areas of west central Alberta, but they have not been associated with specific soil types or parent materials. Se levels in forage samples analysed from 1970 to 1991 have been mapped by legal location (Corbett, 2004).

Low Se soils are also typically deficient in S. The application of S fertilizer (especially sulphate) often reduces Se concentration in forages. Increased yield from S application causes a dilution effect (the same amount of Se in a greater mass) and competition for uptake by plants between sulphate and selenate.

5.11.1 Selenium Results from the Benchmark Sites

Total Se values for the 129 sampling locations were:

Sampling Depth (cm)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
0-15	0.476	0.100	1.6	0.278	58.4
15-30	0.474	0.001	2.3	0.335	70.7

The mean total values are above the normal mean value of 0.3 given by Havlin et al. (1999).

<u>Effect of Soil Properties</u>

Se was significantly correlated with CEC (r = 0.54) and OC (r = 0.55) (Table 1). The mean OC of the 20 locations with total Se of 0.2 or less was only 1.5 %.

<u>Effect of Ecoregion</u>

There were no significant differences in total Se among ecoregions (Table 2). The PL Ecoregion had the highest mean Se (0.65). The MG Ecoregion had the lowest mean Se (0.346), but the variation was low (SD = 0.096; CV = 28 %), resulting in few low Se values (≤ 0.2 mg/kg). Most of the low Se values occurred in the BT Ecoregion, which had the second lowest mean and high variation (SD = 0.253; CV = 88 %) [Table 3].

Effect of Slope Position

Differences among slope positions were relatively small, but in the 0-15 cm depth, Se was significantly higher in the lower slope than in the upper slope (Table 4).

Effect of Management

There was no indication that management practices affected total Se.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Boron

There is no evidence of toxic levels of B at any of the sites. However, a few sites have marginal to deficient levels (< 0.5 mg/kg). Plant analysis would be useful on a few sites to determine if deficient levels occur in plant tissues. Sites were there are significant differences between slope positions should be examined.

6.2 Chlorine

If the critical level of 45 kg Cl ha^{-1} (0-60 cm), identified for the Northern Great Plains Region is valid, many (approximately 40 %) of the benchmark sites are in the potentially deficient range. Limited trials in Western Canada have shown relatively small and inconsistent response to Cl fertilization (personal experience and personal communication with several researchers). Until more definitive results are available, follow-up on the benchmark sites does not appear warranted.

6.3 Molybdenum

There are no reports of Mo deficiency or toxicity in Alberta. No critical values for hot water extractable or DTPA extractable Mo were found in the literature for comparison with the values reported in this study. If further examination of soil Mo is deemed warranted, the Acid Ammonium Oxalate extraction method should be used since it is the most commonly used method reported in the literature. (Note: Mo toxicity in livestock (molybdenosis) has been reported in Manitoba).

6.4 Nickel

There was a fairly wide range in DTPA extractable Ni among the benchmark sites (0.51 to 5.87 mg/kg). The highest value (5.87) approaches the toxic level of 6 mg/kg reported for Bermuda grass. Plant analysis may be warranted on this site to determine if phytotoxicity is an issue.

6.5 Cobalt

Although there are no studies in Alberta that indicate Co deficiency in livestock (Corbett, R., personal communication), salt-licks supplemented with Co are commonly used. Further investigation of soil Co does not appear to be warranted, unless future research indicates Co deficiency for legume crops.

6.6 Silicon

The mean hot water extractable Si values of 137 mg/kg (0-15 cm) and 192 mg/kg (15-30 cm) are much higher than typical values of 3 to 37 mg/kg given for soil solution Si. This indicates that hot water extractable Si may not be comparable to soil solution Si. Plant analysis could be used to determine if plant Si is low at sites with low hot water extractable Si.

6.7 Chromium

None of the benchmark sites have received industrial or municipal wastes. Therefore, Cr toxicity is not a concern. However, given the recent reports of low Cr levels in human diets, Cr analysis of plant materials may be warranted.

6.8 Cadmium

Cadmium contamination of soils from industrial sources is not an issue, and given the Cd content of phosphate fertilizers and the relatively low rates of application used in this region, high Cd levels in crops from these sources is not a concern. However, it would be valuable to examine the Cd content of crops from a few sites with the highest DTPA extractable Cd levels.

6.9 Selenium

All of the total Se values in this study fall within the normal range of 0.1 to 2 mg/kg and the mean of 0.48 mg/kg is above the reported normal mean of 0.3 mg/kg. However, given the prevalence of Se deficiency in livestock in Alberta, it is likely that some of the sites are deficient. Analysis of plant material from some of the sites with low soil Se is recommended.