The Micronutrient and Trace Element Status of Crops Grown on the Alberta Soil Quality Benchmark Sites

Prepared for:

AESA Soil Quality Monitoring Program
Alberta Agriculture, Food and Rural Development
Conservation and Development Branch

Prepared by:

Suzanne Card, Jason Cathcart and Jane Huang
AAFRD, Edmonton

August 2005

Table of Contents

List of Numbered Tables

List of Figures

Executive Summary

Crop micronutrient concentrations of both vegetative tissues and grain, if applicable, were measured from 17 selected AESA Soil Quality Benchmark Sites in the fall of 2003. Entire plants (straw and grain) harvested from three, one m^2, cuts at each topographic location (upper, mid and lower slope position) were analyzed using Inductively Coupled Plasma (ICP) methodologies. Micronutrients analyzed included boron, cadmium, chlorine, copper, iron, manganese, molybdenum, nickel, selenium, silicon and zinc. The purpose of this report is to provide an account of these micronutrient concentrations and to correlate them with a number of selected soil properties including soil pH, organic carbon, sand, silt and clay content, cation exchange capacity (CEC) and calcium carbonate concentrations. In addition, the uptake, translocation and importance of each micronutrient are discussed, as is a summary of the effect of micronutrient partitioning between the grain and straw fraction, the effect of landscape form (i.e., slope position) and the effect of provincial ecoregion on their concentration.

A value of $r \geq \pm 0.4$ was used as an indication of a correlation between micronutrient concentrations and/or select soil parameters. Results indicated that there were 21 correlations to be discussed according to these criteria. Of these, many were not readily explainable, and were likely an artifact of the correlation analysis itself or attributable to a small sample size. In general, differences in plant tissue micronutrient concentration were identifiable as a result of various soil properties, ecoregions and partitioning pattern between the grain and straw components. None of the eleven micronutrients measured differed in response to topographical position.

Note that the interpretation of the straw values, as discussed in this report, is based on an analysis of the entire crop plant harvested at maturity. As such, these values may be somewhat skewed, as this is not the methodology typically employed for assessing nutrient deficiency/sufficiency at this growth stage. At maturity, nutrients are often being actively translocated from the vegetative tissues to the developing grain, and as such grain values are often more representative of nutrient concentration, and as an indication of nutrient sufficiency.

Introduction

In 1998, Alberta Agriculture, Food and Rural Development (AAFRD) established a province wide soil quality monitoring study as part of the Alberta Environmentally Sustainable Agriculture (AESA) Program. The purpose of this ongoing study is to determine the status of soil quality throughout Alberta and to monitor the potential change in soil quality across varying land management practices (Cannon and Leskiw 1999). Forty-two benchmark sites have been established in Alberta for this purpose. These sites, within the Boreal Plains and Prairie Ecozones, are located in the agricultural areas (i.e., white areas) of the province and encompass seven ecoregions: Peace Lowlands (PL); Mid-Boreal Upland (MB); Boreal Transition (BT); Aspen Parkland (AP); Moist Mixed Grassland (MM); Fescue Grassland (FG); and the Mixed Grassland (MG) (Figure 1).

Initial characterization of the Benchmark Sites in 1998 and 1999 resulted in valuable information regarding landform, physical, chemical and biological soil properties in addition to a detailed pedological profile of each of three slope positions (upper, mid and lower) along a catena at each site. Plant and soil sampling is carried out annually to measure soil fertility, plant biomass and crop yield.

In 2002, a thorough (30 element) analysis of the micronutrient status of the soils at the 42 Benchmark Sites was conducted. The purpose of this examination was to assess the soil micronutrient status of the sites in relation to properties such as ecoregion, site characteristics, historic management practices, and deficiencies or toxicities. An analysis of selected data (Penney 2004) revealed that significant regional differences in the 0 to 15 cm depth existed for boron (B), cadmium (Cd) and molybdenum (Mo), and that this difference continued to the 15 to 30 cm only for Cd. Further differences were attributed to slope position, specifically with B, nickel (Ni), cobalt (Co), silicon (Si), Cd, and selenium (Se), where higher concentrations were often identified in lower landscape positions (Penney 2004). Field management had little effect on micronutrient concentrations, although there did appear to be a relationship between soil organic matter and some of the elements tested. In terms of deficiencies and/or toxicities, only Ni was identified as possibly being phytotoxic (one site), and chlorine (Cl) may be deficient for crop production at many of the Benchmark Sites. From a livestock production point of view, low Se may be an element to monitor at some sites in the future.

As a continuation of this project, in 2003, crop tissue samples were collected at 17 of the 42 Benchmark Sites, selected within 6 ecoregions (see Appendix 1). The location of these sites, in addition to the other AESA benchmarks can be seen in Figure 1. Sites were arbitrarily selected so as to ensure wide coverage of the province, topography and soil types. Replicated samples were collected at all three landscape positions (upper, mid and lower) and were sampled from a range of different crop species, including barley, canola, wheat, oat and forage crops. The ability of plants to obtain essential nutrients from the soil is important in dictating where plants are able to grow in the environment, this study

set out to assess the micronutrient status of plant tissue from selected benchmark sites throughout Alberta.

Objectives

Crop tissues (grain and straw, if applicable) from 17 selected AESA Soil Quality Benchmark Sites were analyzed for eleven micronutrients, including: boron (B), cadmium (Cd), chlorine (Cl), copper (Cu), iron, (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silicon (Si), and zinc (Zn). The purpose of this report is to provide an account of the micronutrient concentrations identified in the 2003 crop harvest taken from these sites. Furthermore, it discusses the uptake, translocation and importance of each micronutrient, identifies some in-field characteristics associated with their deficiency or toxicity, and relates this information to:

- Plant partitioning between grain and straw (if applicable),
- The effect of soil properties,
- The effect of ecoregion, and
- The effect of landscape position.

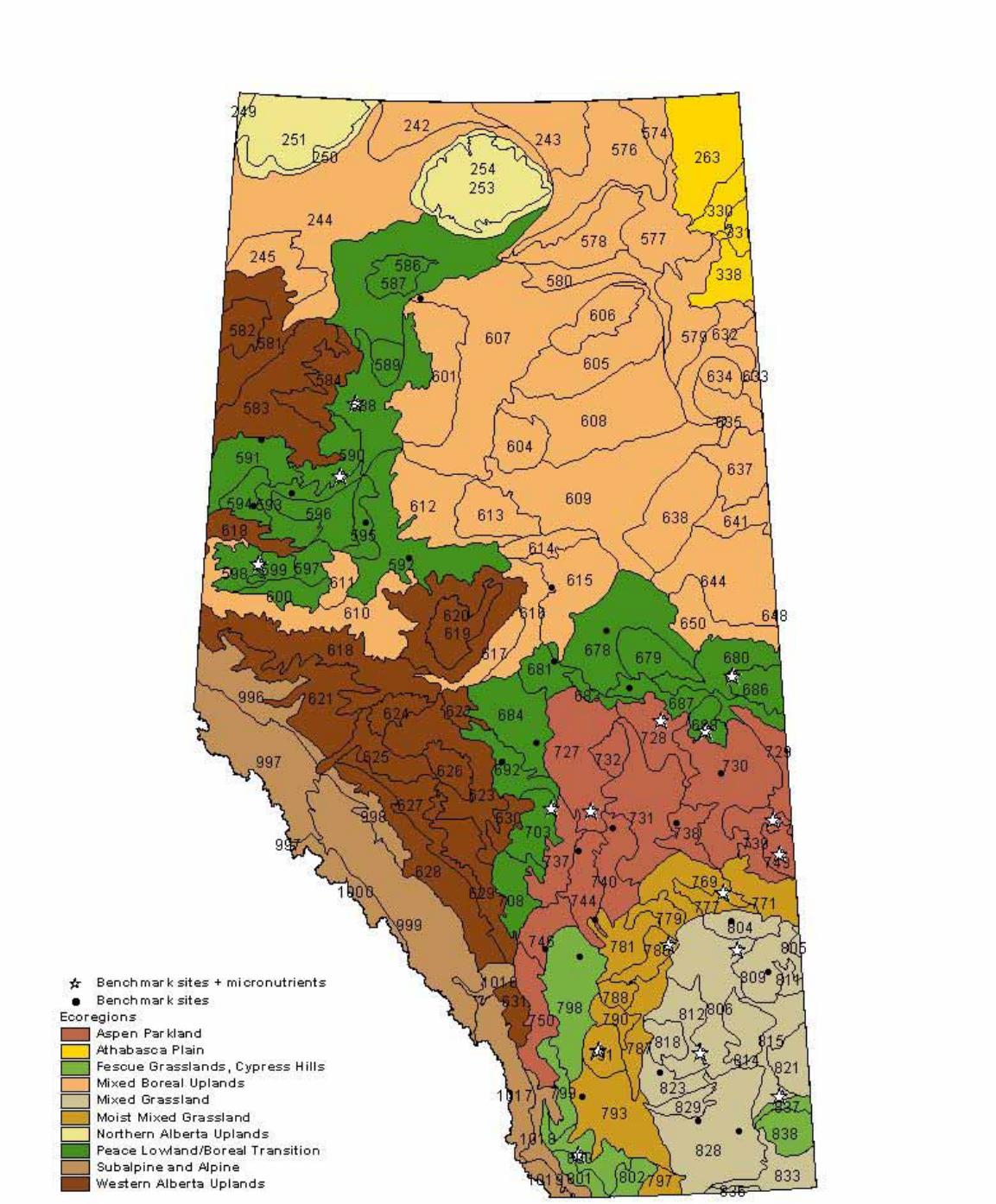

Figure 1. Location of AESA Soil Quality Benchmark Sites and their corresponding ecoregions and ecodistricts in Alberta. Star symbols reflect sites from which tissue analysis was conducted in 2003.

Background

The growth and development of plants is dependent upon not only an adequate supply of moisture and light, but on a supply of numerous mineral nutrients (Marschner 1995). The terms macronutrient and micronutrient are often used to refer to those elements with essential and specific physiological functions in plant metabolism (Romheld and Marschner 1991). Of the 20 identified elements common to plants, nine are considered to be macronutrients, which are elements essential to all plants and which are required in higher quantities. These elements include carbon (C), hydrogen (H), oxygen (O), (which are atmospherically supplied), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and sulfur (S) (Asher 1991). This report will focus on the second group of elements, the micronutrients and/or trace elements, which are often considered just as essential as the macronutrients, but are required by plants in much smaller quantities. What is important to realize is that micronutrient cycles and their specific roles within plant species are not as fully known as those of the macronutrients.

However, the main role of micronutrients where fully identified, tends to be physiological. They are typically found as constituents of prosthetic groups in metalloproteins associated with plant structure, as activators of certain enzyme reactions and/or they, when coupled with potassium, are responsible for osmotic regulation associated with plant turgor pressure (Robb and Peirpont 1983; Romheld and Marschner 1991; Salisbury and Ross 1992). All of these functions are important for the development and maintenance of crop yield. There are eight micronutrients recognized in the literature as being essential to plant growth and development, these include B, Cl, Cu, Fe, Mn, Mo, Se and Zn (Asher 1991, Marschner 1995). There are also a number of beneficial micronutrients which have been found to stimulate plant growth and development, but appear to be essential only under specific conditions and/or for certain plant/crop species. The list of beneficial elements includes Cd, Ni and Si (Marschner 1995).

Many factors in the soil influence the availability of micronutrients, the most important factors being pH and organic matter. With respect to pH, as soils become more acidic, the availability of certain micronutrients is altered (Figure 2). For example, decreasing pH leads to a reduction in the level of available Mo, while the level of Fe and Mn is increased, sometimes to toxic levels, as are the levels of B, Ca, and Zn. Greater soil acidity also reduces the CEC of soil organic matter, resulting in changes in the level of these micronutrients in the soil solution, which ultimately affects plant availability.

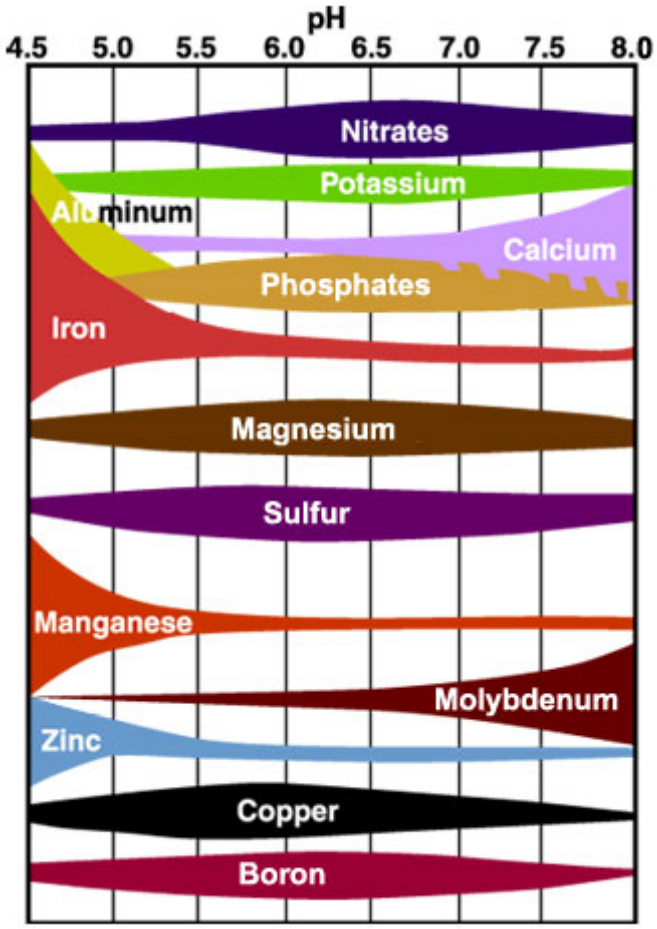

Figure 2. The effect of soil pH on controlling the availability of selected [micro] nutrients in soil (*Source:* Traylor Chemical and Supply Company, Inc. Orlando, FL).

From a soil perspective, crop micronutrient deficiencies in Alberta are less common than in other regions of the world. This has been attributed the relatively young age of our soils (approximately 10,000 years old), low precipitation and the slow rate of weathering experienced in Alberta, and the fact that our soils have only been under agricultural cultivation for 50 to 100 years as compared to other countries which have been cultivated for thousands of years (i.e., less time for plant/crop removal).

Diagnosing nutrient deficiencies

The importance of being able to measure nutrient deficiencies in a growing crop leads to better fertilizer management for that crop. Proper management of nutrients will ultimately result in improved production (i.e., yield potential) and crop growth rates, along with reduced crop inputs (i.e., fertilizer) and ultimately reduced potential for nutrient losses to the environment (Mankin and Fynn 1996).

In general, nutrient deficiencies in crops may often be identified by simple examination of the physical condition (particularly colour and smoothness of the leaf edges) of certain

leaves on the plant. Typically, during the early stages of crop growth, the upper most fully expanded leaf is used as an indicator of crop nutritional status, as it is the leaf which is behaving most like a "physiological sink" for incoming photosynthate (sugars) from newly formed/forming leaves. However upon anthesis, the leaf sub-tending the reproductive structure is the preferred leaf for diagnosing mineral deficiencies, particularly N (Asghari and Hanson 1984). This leaf is often designated as the "new" sink location during reproductive development due to the translocation of nutrients to the developing seed during seed fill.

As photosynthesis in the leaves represents a "physiological source" of all translocatable sugars in the plant, it is essential to maintain adequate mineral nutrition at these sites. Marschner (1995) explains that there are a number of ways in which mineral nutrition of plants influences photosynthesis. These include the involvement of mineral nutrients in the electron transport chain of the thylakoid membrane, detoxification of O_2 radicals, photophosphorylation, and in chloroplast formation itself. If an insufficiency of any essential nutrients exists, then the chloroplasts that are formed will possess lower photosynthetic capabilities, thus producing less photosynthate, and ultimately decreasing crop growth and yield.

In addition to the physical appearance of crop leaves, the concentration of nutrients in various plant parts has long been used as a method of assessing the nutrient status of agricultural crops (Asghari and Hanson 1984). Using nitrogen as an example, Novoa and Loomis (1981) provide an example as to how nutrient concentration may be used. Assuming a 1.6% N concentration in mature wheat biomass and assuming that a total biomass yield of 15 t ha^{-1} is attainable suggests that approximately 240 kg N ha^{-1} is required to fertilize the crop (15,000 x 0.016). Further refining this recommendation by basing the requirement on an 80% uptake efficiency for wheat, then 300 kg N ha^{-1} needs to be available to the growing crop. This said, it is important to remember the relatively high nitrogen supplying capability of Alberta soils.

Methodology

Soil sampling and analysis

The detailed site selection and sampling protocols used for the AESA Benchmark Sites are described by Leskiw et al. (2000) and Cannon (2002), therefore only a general description is provided here. As part of the initial site pedological investigation, samples from three or four of the principle soil horizons (A, B, BC and/or C) were collected and analyzed by Norwest Labs, Edmonton, AB. The analyses included: particle size by hydrometer (for texture measurements), cation exchange capacity (CEC), pH in $CaCl_2$ and H_2O, electrical conductivity (EC) in a saturated paste extract, sodium adsorption ratio (SAR, which was calculated from soluble Ca, Mg, and Na ions of the saturated paste, when EC was greater than four), total N, organic carbon and calcium carbonates ($CaCO_3$). In addition to the chemical analysis, the sites were fully characterized and photographed. Characterization included information on slope, aspect, parent materials,

drainage, bulk densities and erosion potential, to name but a few. A full description of this characterization is maintained in the AESA Soil Quality Benchmark database.

In addition to the initial investigation, the benchmark sites are relocated each year using either a Trimble AgGPS132 or a Satloc SLXg GPS receiver (as no permanent markers are left in the field), and soil and crop samples are collected, analyzed, and the data recorded in the Soil Quality Benchmark database. Annual soil sampling occurs in the upper, mid, and lower landscape positions along a transect (i.e., catena), where at each landscape position a composite sample of 5 to 10 cores is collected at both the 0 to15 and 15 to 30 cm depths following crop harvest, but prior to fertilization and freeze-up. These samples are then analyzed for soil fertility (i.e., NH_4, NO_3, P, K, SO_4, pH_w, pH_c, EC, light-fraction mass, -carbon, -nitrogen, and OC) and the bulk density of the A horizon. Correlations between the 2003 plant micronutrient levels and the specific soil parameters made in this report made use of the 2003 annual soil database in addition to data collected during the initial pedological investigation in 1998, 1999 or 2000 (one site).

Plant destructive harvests

As mentioned above, in addition to soil samples, crop samples are also harvested and analyzed on an annual basis. A detailed description of the plant sampling techniques employed at each of the Benchmark Sites can be found in Cannon (2002). In general, once the sites have been relocated (during the growing season), crop tissue is clipped to ground level, ensuring that no stubble remains. The quantity of plant material harvested is dependent upon whether the rows are discernible and the density of the standing crop. If the rows are discernible, four rows are collected, each one meter in length (i.e., $1m^2$). If the rows are discernable, but the crop is thin, at least 8 rows are harvested ($2m^2$). In cases where the rows are not discernable, square meter cuts are harvested from normal stands, and 2 m^2 is harvested from thin stands.

Clipped samples are bagged and labeled, and allowed to air dry. They are then dried in forced air ovens at 50ºC for 24 hours. Crop yield (grain and biomass) is calculated from the dried material, and a sub-sample of both the grain and biomass (forage) is sent to the lab for quality analysis. This analysis includes moisture, protein, calcium, phosphorous and additionally for the oilseeds, oil content; and the forages, Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF).

Micronutrient analyses

In 2003, analysis of the plant material included a chemical analysis for micronutrients in both grain and straw. The elements analyzed were: B, Cd, Cl, Cu, Fe, Mn, Mo, Ni, Se, Si, and Zn. The elements B, Cl, Cu, Fe, Mn, Mo and Zn were extracted with the Inductively Coupled Plasma (ICP) Spectroscopic Method (AOAC 1997). The elements Cd, Ni, Se and Si were also analyzed using a variant of the ICP Spectroscopic method.

Data analyses

Descriptive statistics (i.e., mean, min, max, standard deviation (SD) and the coefficient of variation (CV)) on the concentration (mg kg^{-1}) of each of the micronutrients was performed in MS Excel. These results were then correlated (r) to each of the other

micronutrients and to select soil properties to identify possible relationships and/or causal factors for their observed levels. Following the descriptive analysis, an Analysis of Variance (ANOVA) was performed on all experimental variables using the general linear models (proc GLM) procedure of SAS ver. 9.1 (SAS Institute Inc.). The probability of making a Type-1 (α) error was set 0.05 to test the significance of main effects and their interactions.

The influence of eco-region, slope position and crop part (i.e., grain versus straw) on soil micronutrients was analyzed using a three factor ANOVA. In most of the eco-regions, there was only one representative sample for that region. As a result, the interaction effects on micronutrients could not be addressed. Furthermore, since the sample size was small (i.e., in most cases, there was only one sample for each eco-region x slope position x crop plant part group), it was extremely difficult to make any direct claims about the normality and equal variances assumption required for the ANOVA procedure. This said, in cases where significant main effects were identified, means were compared using Tukey's Studentized Range Test.

Samples collected from the oat crop were not included in the ANOVA as there was only one site from which data was available. Forage samples collected included tissue from multiple cuts (see Appendix 1). These were designated to three groupings; cut 1, in which the sample was taken early in the growing season, cut 2, in which the sample was taken later in the growing season (i.e., following cut 1 in the same field), and cut 3, which included the sites from which only one cut per season was taken, independent of the time in the growing season. For analysis purposes, cuts 1 and 3 were combined as a "first cut", and a two-way ANOVA run on the data, including only the slope and region variables.

Results and Discussion

Examination of the summary tables for the micronutrient analyses (Tables 1 through 4) and the interpretation of the values found therein, needs to be met with some caution. The analyses discussed in this report were based on a single years value, and with respect to the straw component, were measured from a sub-sample of the entire harvested plant. Although suitable for grain analysis, normal tissue sampling is often much more directed towards certain plant parts (i.e., upper leaves, petioles, etc.), than what was economically and physically possible in this project. As such, results may be somewhat skewed until sufficient data is available to confirm the results presented herein. For this reason, it is suggested that tissue micronutrient concentrations be analyzed periodically throughout the duration of the AESA Soil Quality Benchmark Program to obtain greater confidence in their values. A more detailed description of the results found in these tables follows below, under the section for each individual micronutrients.

Crop tissue concentrations from the eleven micronutrients were correlated (Table 1) against selected soil parameters including pH in water and $CaCl_2$, organic carbon (OC), potassium (K), phosphorus (P), sand, silt, clay, CEC, and $CaCO_3$. An assumed

correlation coefficient (r) of ≥0.4 was used as a limit to indicate a possible relationship between the micronutrients themselves and select soil parameters. Not surprisingly, the highest correlation occurred between pH in H_20 and $CaCl_2$ (r=0.98), which will not be discussed in this report. Other significant correlations include CEC and OC (r=0.87), $CaCO_3$ and B (r=0.70) and P and K (r=0.71). There was also a highly negative correlation between clay and sand (-0.80), which seems reasonable, as these are two of the main soil textures found throughout Alberta.

Tables 2 and 3 outline the effect of ecoregion and slope, respectively, on the mean micronutrient concentrations of barley, wheat, canola and forage crops. Note that not all crops occurred in all ecoregions of the province. For example, there are no measurements made on forages in the Aspen Parkland or Peace Lowlands, and likewise, there are no measurements on barley or canola in the Mixed Grasslands. This is partly indicative of where certain crops are grown provincially, and of the AESA Soil Quality Benchmark programs desire to best represent the cropping systems of the ecoregions in which the benchmarks are found.

The partitioning of micronutrients between grain and straw in barley, wheat and canola is illustrated in Table 4. Under certain situations, it may be important to know where these nutrients are found in the crop tissue, particularly from the livestock/human health perspective. Interestingly, significant differences between tissue parts occur in 9 of 11 (82%) micronutrients for both barley and canola, and only 6 of 11 (55%) for wheat. Of the measured differences, certain elements Cd, Si, Cl, and B tend to remain in higher concentrations in the straw, whereas other elements, Ni, Cu, and Zn remain higher in the grain component.

Following Tables 1 through 4, is a more detailed discussion of each of the eleven micronutrients analyzed in this report. Within each of these sections, micronutrient deficiencies are discussed. Micronutrient deficiencies depend on either the function(s) of the element in question and/or on the translocation ability of the element within the plants structure. Generally, deficiency symptoms differ according to plant species, growth stage and the complexities associated with multi-element deficiencies. Furthermore, environmental conditions and the time of day in which sampling occurs influences the degree of accuracy obtained in the measurements. A comparison of the AESA Soil Quality Benchmark micronutrient data to that found in the literature, revealed that published deficiency levels of each micronutrient vary between sources in the literature. As such, only a general overview of the literature findings is presented for each micronutrient assessed.

As mentioned, testing for nutrient deficiencies should be specific to each plant species, and proper sampling and handling procedures must be followed in order to ensure reliable results. Typically, an adequate sample must contain between 20 and 50 individual plants (McKenzie 1998). Sampling should occur the morning, during cool conditions, as hotter temperatures often induce heat and moisture stress, which may alter the analysis results. Some species of plants, particularly wheat, require the entire above ground portion of the plant to be taken for analysis at a specific period in the plants

growing period. Other sampling protocols may be specific to the nutrient in question. For example, when testing for a boron deficiency, it is necessary to sample an actively expanding plant part, such as a young leaf, in order to accurately determine current boron supply (Bell 1997). Sampling procedures in our study included collecting three plant samples, consisting of the entire above ground portion, per landscape position (upper, mid and lower). Therefore, care must be taken when interpreting the deficiency information in relation to the results obtained in this study.

Although a great deal of information is presented under each heading, this is by no means an exhaustive discussion for each element. The approach taken in this report was to highlight some of the important factors and information regarding each of the micronutrients, not to provide a definitive description for each. For further information, readers of this report are encouraged to examine other texts and references on the subject, including the works of Brady (1990); Salisbury and Ross (1992); Tisdale et al. (1993) and Marschner (1995).

Table 1. Correlation coefficients (where r ≥ 0.40) between crop micronutrients and selected soil properties from the AESA Soil Quality Benchmark Sites.

	Cd	Ni	Se	Si	Cl	B	Cu	Fe	Mn	Mo	Zn	pH_W	pH_c	OC	K	P	Sand	Silt	Clay	CEC	$CaCO_3$
Cd	1.00																				
Ni		1.00				**0.43**															
Se			1.00																		
Si				1.00	**0.47**						**-0.43**									**0.43**	
Cl					1.00						**-0.41**										**0.54**
B						1.00						**0.52**	**0.49**								**0.70**
Cu							1.00				**0.50**										
Fe								1.00													
Mn									1.00												
Mo										1.00											
Zn											1.00						**-0.49**				
pH_W												1.00	**0.98**								**0.55**
pH_c													1.00								**0.55**
OC														1.00				**0.45**		**0.87**	
K															1.00	**0.71**					
P																1.00					
Sand																	1.00	**-0.62**	**-0.80**	**-0.56**	
Silt																		1.00		**0.44**	
Clay																			1.00		
CEC																				1.00	
$CaCO_3$																					1.00

Table 2. Mean micronutrient concentrations for barley, wheat, canola and forage crops harvested from the AESA Soil Quality Benchmark Sites in their corresponding ecoregions of Alberta.

	Barley			Wheat			Canola			Forages		
Micronutrient	**FG**	**PL**	**AP**	**AP**	**MG**	**MM**	**AP**	**MM**	**PL**	**BT**	**MG**	**MM**
Cd	0.08a*	0.06	0.02b	0.07b**	0.26a	0.12b	0.05b***	0.12a	0.07b	0.03a	0.07a	0.11a
Ni	0.26b	0.36	0.19b	0.42a	0.39a	0.46a	0.32b	0.88ab	0.88a	0.90a	1.47a	1.09a
Se	0.64a	0.54	0.43a	0.45b	0.92a	0.43ab	0.56a	0.63a	0.53a	0.36a	0.74a	0.43a
Si	340.61a	435.0	231.48b	214.02b	340.54a	267.17ab	31.74b	75.89a	55.29ab	381.39a	67.27b	283.11a
Cl	0.06b	0.67	0.31ab	0.20a	0.38a	0.17a	0.29a	0.09a	0.27a	0.53a	0.36a	0.28a
B	3.06a	3.43	4.89a	5.44a	3.96ab	2.17b	23.31a	13.78b	20.19ab	8.32b	47.22a	11.84b
Cu	9.22a	7.84	8.29a	9.79a	6.88a	6.76a	4.19a	2.62a	3.20a	2.79b	8.17a	3.47b
Fe	63.88b	155.74	65.66b	75.24b	93.29b	142.17a	62.69a	85.43a	85.28a	213.23a	93.33a	125.32a
Mn	17.38b	27.86	13.52b	52.88a	23.68b	73.03a	29.74a	28.64a	29.10a	71.00a	22.11b	35.40ab
Mo	0.57a	0.59	0.82a	0.79a	0.66a	0.53a	2.54a	0.65a	0.77a	0.91b	2.21a	0.87b
Zn	29.74b	40.59	29.29b	27.95a	29.07a	27.66a	28.63a	26.00a	24.57a	12.51a	19.75a	22.06a

* Means followed by different letters within a crop and mineral element are significantly different at p<0.05
** The data is not balanced as AP region had 12 samples and MG and MM had 6
*** The data is not balanced as AP has 6 samples, MM has 4, and PL has 12

Table 3. Effect of slope position (upper, mid and lower) on micronutrient concentration in barley, wheat, canola and forage crops harvested from the AESA Soil Quality Benchmark Sites.

	Barley			Wheat			Canola			Forages		
	Slope Position			Slope Position			Slope Position			Slope Position		
Micronutrient	Upper	Mid	Lower	Upper	Mid	Lower	Upper	Mid	Lower	Upper	Mid	Lower
Cd	0.05a*	0.06a	0.06	0.11	0.13	0.16	0.09	0.07	0.06	0.04	0.06	0.10
Ni	0.26a	0.29a	0.26	0.42	0.44	0.42	0.78	0.66	0.75	1.25	0.98	1.27
Se	0.57a	0.57a	0.47	0.53	0.77	0.39	0.55	0.61	0.49	0.61	0.59	0.37
Si	331.28a	338.92a	336.89	268.33	259.38	249.10	60.44	53.36	40.90	234.13	235.32	238.81
Cl	0.38a	0.31a	0.35	0.21	0.24	0.26	0.24	0.25	0.23	0.39	0.40	0.43
B	4.06a	3.39a	3.93	4.10	4.04	4.62	19.19	19.53	21.24	25.37	24.13	24.25
Cu	9.77a	6.02a	9.57	8.68	10.88	5.35	3.53	3.46	3.03	4.93	5.23	5.08
Fe	89.98a	114.32a	80.99	110.85	90.42	88.19	85.28	81.80	67.43	118.88	200.84	123.35
Mn	17.46a	20.12a	21.17	43.15	46.48	62.22	30.15	30.25	26.49	42.81	57.98	32.18
Mo	0.78a	0.60a	0.59	0.66	0.55	0.87	0.70	2.05	0.85	1.37	1.45	1.43
Zn	33.29ab	29.52b	36.82	23.23	29.05	32.20	24.18	24.15	30.66	15.08	14.80	22.06

* Means followed by different letters within a crop and mineral element are significantly different at $p<0.05$

Table 4. Mean micronutrient concentrations for barley, wheat and canola crops differentiated by crop plant part (grain or straw) harvested from the AESA Soil Quality Benchmark Sites.

	Barley		Wheat		Canola	
Micronutrient	**Grain**	**Straw**	**Grain**	**Straw**	**Grain**	**Straw**
Cd	0.03b*	0.08a	0.09b	0.17a	0.04b	0.11a
Ni	0.29a	0.25a	0.51a	0.34b	1.06a	0.40b
Se	0.62a	0.46b	0.59a	0.54a	0.63a	0.48a
Si	126.25b	545.15a	20.49b	497.39a	38.25b	66.82a
Cl	0.15b	0.54a	0.08b	0.40a	0.10b	0.38a
B	2.20b	5.39a	4.70a	3.81a	14.01b	25.74a
Cu	14.24a	2.66b	14.12a	2.49b	4.01a	2.73b
Fe	90.54a	99.65a	70.94b	122.03a	106.55a	51.75b
Mn	15.85b	23.32a	51.01a	50.22a	40.94a	17.44b
Mo	0.79a	0.53b	0.72a	0.67a	1.68a	0.78a
Zn	47.21a	19.21b	43.78a	12.54b	42.61a	9.26b

* Means followed by different letters within a crop and mineral element are significantly different at $p<0.05$

Boron (B)

Boron is considered an essential plant nutrient, however the role that boron plays in plant nutrition is considered to be one of the least understood of the micronutrients (Marschner 1995). In order to utilize this element, plants take-up undissociated boric acid (H_3BO_3) from the soil solution (Fleming 1980). This is then transported throughout the plant in the xylem, where it can be found in relatively high concentrations in both the leaf tips and leaf margins, the zones where water is being actively transpired from the plant (Mengel and Kirkby 1987). Although slow to translocate, boron functions mainly in cell wall formation and stabilization, lignification, and xylem differentiation (Romheld and Marschner 1991). Boron, however, is also involved in plant reproduction, germination of pollen (Nyborg and Hoyt 1970), and the elongation of the pollen tube itself, all areas where its concentration can be nearly twice that typically found in the plant stems. Boron is necessary for normal plant growth, particularly in canola and legume crops (Evans and Solberg 1998), where it promotes crop maturity, water balance, flower set, and crop yield.

Generally, the boron requirements of dicotyledon crops (i.e., broadleaf) are much higher than monocotyledon crops (i.e., grasses, Fleming 1980; Jones 1991; Welch et al. 1991). Crops that require higher levels of boron include alfalfa, and a number of horticultural crops including beets, turnips, apples, cabbage, and cauliflower, which are not widely produced in Alberta (Welch et al. 1991).

Boron Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	6.68	0.80	20.90	5.86	87.69
Straw	105	11.10	0.80	39.40	11.04	99.49
Forage	63	27.57	3.00	57.80	18.13	65.79

Mean boron values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	3.18	3	13.63	4	6.87	1	0.80
M	**Grain**	3	1.49	4	13.72	4	3.22	1	0.90
U	**Grain**	3	1.93	4	14.59	4	4.02	1	1.80
L	**Straw**	3	4.69	3	28.86	4	2.38	1	8.73
M	**Straw**	3	5.30	4	25.35	4	4.86	1	1.10
U	**Straw**	3	6.18	4	23.78	4	4.19	1	1.23

Effect of soil properties

Boron was significantly correlated with Ni (r=0.43), pH in both water (r=0.52) and $CaCl_2$ (r=0.49), and with $CaCO_3$ (r=0.70) (Table 1).

Soil pH is one of the factors known to affect the boron content of plants (Welch et al. 1991). When soils reach a pH of greater than approximately 6.5 to 7.0, the availability of boron decreases (Figure 2) due to its adsorption onto clay and hydroxy-Al surfaces (Moraghan and Mascagni 1991). At a pH below 7, H_3BO_3 is not adsorbed very readily by the colloidal fraction making it more plant available. Therefore, we would expect to see a negative relationship between pH and boron. However, the soil pH for the ecoregions included in this study ranged from a mean of 5.31 to 7.75, with only five sites (588, 703, 806, 812, and 815) having pH_w over 7 (Appendix 2 and 2.1). These pH values are well within the range at which boron is most readily available. This, combined with the small sample size may explain the positive correlation that was obtained for this element (Table 1, r=0.52).

The availability of boron to plants is decreased under higher pH conditions and this is further amplified in calcareous soils (Marschner 1995). Calcium carbonate is an adsorbing surface for boron, thereby reducing the availability of H_3BO_3 to plants. Similar to the relationship with pH, we would expect to see a negative correlation between calcium carbonate and boron. The resulting positive relationship may also be attributed as being an artifact of a small sample size and the relatively low pH values found at the majority of sites in this study.

A review of the literature was inconclusive in indicating any known relationships between nickel and boron in plants, and as such the relationship between these two elements appears to be an artifact of the calculation procedure.

Effect of ecoregion

A significant difference in boron concentrations in the wheat samples was found between the Aspen Parkland, Mixed Grassland and the Moist Mixed Grassland ecoregions (Table 2). Wheat growing in the Aspen Parkland had the highest boron levels, which differed significantly from the low levels found in the Moist Mixed Grassland. The finding that the Moist Mixed Grassland had the lowest boron levels coincides with those of Pawluk and Bayrock (1969), who identified that the lowest levels of soil boron typically occurred in soils found in southeast Alberta, and that the concentration tended to increase moving northwestward from that region. Canola samples were also found to differ significantly in their boron concentration. Similar to wheat, the Aspen Parkland had the highest levels, which were significantly different from canola grown in the Moist Mixed Grassland. With respect to the barley crops, boron concentration did not appear to differ based on ecoregion (Table 2). In contrast to what might be expected according to the findings of Pawluk and Bayrock (1969), forage sample results indicate that the Mixed Grassland had the highest concentration of plant tissue boron, with both the Boreal Transition and Moist Mixed Grassland having the lowest concentration. In general, we would expect that the Peace Lowland would have the highest levels of boron, based on the findings of Pawluk and Bayrock (1969). However, this was not the case in this study, as the Aspen Parkland exhibited the greatest concentration of this micronutrient.

Effect of slope

There was no significant difference in boron levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Boron levels in straw were found to be significantly higher than in grain for both the barley and canola crops (Table 4). The wheat crop did not differ significantly in boron concentration between the grain and the straw, however the grain did tend to have higher levels (4.70 mg/kg and 3.81 mg/kg respectively). Boron functions in plants mainly in cell wall formation, stabilization and lignification (Romheld and Marschner 1991) therefore the findings of high boron levels in the straw samples can be readily explained as being structural.

Diagnosing boron deficiencies

Deficiency symptoms are not common in most areas, yet disorders associated with the disintegration of internal tissues have been identified under certain circumstances. This disorder is known as "heart-rot" in beets, or "stem crack" in celery (Salisbury and Ross 1992). The most common deficiency symptom, however, is the failure of root tips to elongate normally (Salisbury and Ross 1992). There are a wide variety of symptoms associated with boron deficiencies, and they are all dependant on plant species and age. Further, the literature reports a relatively wide range of values for crop sufficiency, depending on crop age and sampled part (Raven et al. 1999, Welch et al. 1991, Romheld and Marschner 1991, Jones 1991). In Alberta, deficiencies of boron have been suspected in canola and alfalfa crops growing in sandy-textured Grey Wooded soils (McKenzie 1992).

Typical boron concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998).

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<20	20 - 30	30
Cereals[2]	3	3 - 5	5
Canola[3]	<20	20 - 30	30

1. Based on the upper 15 cm at 10% bloom
2. Whole plant prior to filling
3. At flowering

Cadmium (Cd)

Although cadmium is considered to be a required element by animals, it is not considered essential for higher plant life (Welch et al. 1991). In fact, at certain concentrations it has been identified as being toxic to both plants and animals owing to its ability to disrupt enzyme activity (Mengel and Kirkby 1987). Sources of cadmium to the agricultural environment include metal smelters and sewage sludge application. The application of sewage sludge to agricultural lands and the draining of mine waters on rice crops have resulted in cadmium toxicity to both livestock and humans (Welch et al. 1991). In these cases, excess cadmium bioaccumulates, where it has been observed to cause kidney damage, rhinitis, emphysema and Itai-Itai disease (Mengel and Kirkby 1987). Despite these possible detrimental effects, there have been some beneficial effects of this element to crop production, including the suppression and increased resistance to diseases, such as of powdery mildew (Graham and Webb 1991).

As cadmium is structurally very similar to zinc, it often mimics zincs behavior in terms of plant uptake and metabolic function. Its availability depends not only on soil pH, but also on the presence of other cations, such as calcium and zinc. Increasing pH, clay content and/or humus content of the soil are known to decrease the availability of cadmium through its binding to soil and organic matter particles. The exact ability of plants to accumulate cadmium varies significantly both between plants and among genotypes within a given species. Accumulations of excessive cadmium concentrations have occurred in leafy vegetables and has been observed to disturb iron metabolism to such an extent as to cause leaf chlorosis.

Cadmium Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	0.05	0.02	0.34	0.06	117.38
Straw	105	0.12	0.02	0.42	0.08	68.00
Forage	63	0.06	0.02	0.29	0.06	100.29

Mean cadmium values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	0.03	3	0.04	4	0.11	1	0.02
M	**Grain**	3	0.03	4	0.04	4	0.08	1	0.02
U	**Grain**	3	0.03	4	0.05	4	0.08	1	0.02
L	**Straw**	3	0.08	3	0.09	4	0.21	1	0.02
M	**Straw**	3	0.08	4	0.10	4	0.18	1	0.03
U	**Straw**	3	0.08	4	0.13	4	0.14	1	0.05

Effect of soil properties
Cadmium was not correlated with any soil properties or any of the elements included in the plant tissue analysis (Table 1).

Effect of ecoregion
Cadmium levels in barley were found to differ significantly between the Fescue Grassland, Peace Lowland and the Aspen Parkland (Table 2). Both the Fescue Grassland and the Peace Lowland had higher levels than the Aspen Parkland. Cadmium levels in wheat also differed significantly between the ecoregions. The Mixed Grassland ecoregion had significantly higher levels of cadmium than the Moist Mixed Grassland or the Aspen Parkland. The canola crop samples showed significantly higher levels of cadmium in the Moist Mixed Grassland ecoregion compared to the Aspen Parkland and Peace Lowland ecoregion. Forage crops did not differ significantly between ecoregions.

Effect of slope
There was no significant difference in cadmium levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw
Significantly higher concentrations of cadmium were found in the straw samples for barley, canola and wheat (Table 4). This reflects the results of Olek and Filipek (2005) who found in their study of spring barley, that in mineral soils, cadmium concentrations were typically higher in the straw. Similarly, Risser and Baker (1990) concluded that concentrations of cadmium were greatest in plant roots rather than vegetative parts, but vegetative parts were generally greater in cadmium concentration than that found in the seed.
Accumulation of cadmium generally occurs in the root tissue, but it is easily transported to all parts of the plant. Cellular sequestration of cadmium can occur, particularly in the vacuole, and this can influence the movement of cadmium throughout the entire plant (Hart et al. 1998). Perhaps compartmentalization occurred more frequently on samples in this study thereby reducing the amount of cadmium found in the grain. Another explanation may be the occurrence of a low level of chlorine in the soils at the sites included in this study. An increase in the concentration of soluble chlorine has been found to enhance the accumulation of cadmium in the grain, specifically in wheat (Norvell et al. 2000).

Diagnosing cadmium deficiencies
There is very limited information regarding deficiency levels of cadmium in plants, as most information focuses on toxicity levels. However, Risser and Baker (1990) suggest that tolerance levels for cadmium in plants is approximately 1 mg/kg.

Chlorine (Cl)

Of all the micronutrients, chlorine was the last to be considered essential for plants due in part to its abundance in both the lithosphere and atmosphere (Jones 1991; Romheld and Marschner 1991). Most plants can absorb upwards of 10 to 100 times as much chlorine as they require, and are often assumed to be luxury consumers of this element. The ability of plants to access these quantities of chlorine is associated with the fact that chlorine is not readily adsorbed by soil minerals, and is considered to be one of the most mobile of the plant nutrients (Mengel and Kirkby 1987). Depending on moisture conditions, this mobility may in fact lead to leaching of this element from the soil profile resulting in deficiencies in crops.

Approximately 130 chloride-containing compounds have been identified in the plant kingdom (Salisbury and Ross 1992). Plants utilize chlorine as the chloride (Cl^-) anion, which is easily taken up and is highly mobile within the plant tissues (Romheld and Marschner 1991). Soil pH, specifically low pH, promotes the uptake of the chlorine anion through a protonated carrier system. Once the plant has absorbed chlorine, it is required for photosynthesis as it stimulates the oxidation of water (Jenkins and Jones 1980; Salisbury and Ross 1992) and it functions in both charge compensation and osmoregulation processes, such as turgor pressure associated with plant water content (Fixen et al. 1986; Romheld and Marschner 1991). Benefits of trace levels of chlorine in the plant have included the control of "take all" (root rot) disease in both wheat and barley crops (Brady 1990; Evans and Solberg 1998).

Chlorine Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (%)	Minimum (%)	Maximum (%)	SD	CV (%)
Grain	105	0.10	0.04	0.25	0.05	49.90
Straw	105	0.45	0.04	1.22	0.34	75.40
Forage	63	0.51	0.15	1.00	0.22	44.02

Mean chlorine values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	0.16	3	0.11	4	0.08	1	0.06
M	**Grain**	3	0.15	4	0.10	4	0.07	1	0.12
U	**Grain**	3	0.14	4	0.09	4	0.07	1	0.12
L	**Straw**	3	0.54	3	0.35	4	0.44	1	0.27
M	**Straw**	3	0.46	4	0.39	4	0.41	1	0.70
U	**Straw**	3	0.62	4	0.39	4	0.36	1	0.94

Effect of soil properties

Chlorine concentrations were significantly correlated with Si (r=0.47), Zn (r=-0.41) and $CaCO_3$ (r=0.54)(Table 1).

Both chlorine and silicon are known to play a role in disease resistance in plants (Evans and Solberg 1998). Whereas chlorine is readily imported into leaf cells (Romheld and Marschner 1991), silicon is located mainly in the cell walls. Chlorine is also known to react with silicon to form 'silicon (IV) chloride'. A review of the literature did not indicate any direct relationships between chlorine and silicon as they relate to plant growth and metabolism. Furthermore, there does not appear to be an exact reason for the observed correlations between chlorine and Zn or $CaCO_3$. It is likely however that these correlations are either pH dependent or an artifact of the calculation.

Effect of ecoregion

Chlorine levels were not found to be significantly different between ecoregions for the wheat, canola, and forage crops sampled in this study (Table 2). Chlorine levels did, however, differ significantly between barley samples in the Fescue Grassland, Peace Lowland and Aspen Parkland. Barley being grown in the Peace Lowland had a significantly higher concentration of chlorine than barley being grown in the Fescue Grassland.

Effect of slope

There was no significant difference in chlorine levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Concentrations of chlorine in the barley, canola, and wheat straw were higher than in the grain (Table 4). This is supported by the work of Jones (1991) who identified that chlorine is not evenly distributed within plants parts, and that differences between chlorine accumulation in various plant parts occur most frequently in non-halophytes, or plants that flourish under non-saline conditions (White and Broadley 2001). Generally, older leaves have higher concentrations than younger leaves, which is a limitation in this study, as the analysis was performed on a sub-sample of the entire plant. In both halophytes (saline-loving) and non-halophytes (i.e., glycophytes) shoot tissues tend to have higher concentrations of chlorine than reproductive (floral) tissues. In order to support plant growth, the majority of chlorine is loaded into the xylem from the soil via the root system. Therefore, the concentration of chlorine in tissue from the fruits and seeds is generally lower, as this tissue is supplied with chlorine through the phloem.

Diagnosing chlorine deficiencies

Although very rarely deficient in soil owing to its high solubility, vast quantity in the atmosphere, and its indirect application through fertilizers such as KCl (Mengel and Kirkby 1987; Brady 1990), chloride deficiency symptoms include a reduction in plant growth and the development of chlorotic (yellow) and/or necrotic (dead) spotting on leaf tissue (Salisbury and Ross 1992). In extreme cases, complete bronzing of the leaf may

occur. Below the soil surface, chlorine deficiency may result in root stunting. A much larger concern is chlorine toxicity, which results in a limitation in plant growth (Marschner 1995). In Alberta, chlorine is not known to be deficient (McKenzie 1992) as concentrations tend to be greater than the 100 mg kg^{-1} (0.01%), suggested as being in the adequate range for most plants (Jones 1991 and Raven et al. 1999), and the critical concentration of 1.5 g kg^{-1} (0.15%) for the aboveground plant at head emergence for wheat (Fixen et al. 1986).

Copper (Cu)

Plants take up copper, an essential plant nutrient, as Cu^{2+}. Concentration of copper in plants is dependent upon the species, stage of growth, the plant part, and on various soil properties (Welch et al. 1991). As an essential plant nutrient, it is considered an integral component of photosynthesis and respiration processes (Romheld and Marschner 1991; Hall and Williams 2003) and in the functioning of both the detoxification of superoxide radicals and cell wall lignification (Romheld and Marschner 1991). Copper is also present in the enzymes associated with oxidation and reduction. Crops with high copper needs include wheat and barley, whereas canola and rye have very low copper requirements (Solberg et al. 1999). Worldwide, copper deficiency is quite rare (other than in Australia) because it is needed in such small quantities (Salisbury and Ross 1992).

Copper Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	9.99	1.70	41.60	9.88	98.83
Straw	105	2.53	1.20	14.40	1.39	54.91
Forage	63	6.05	1.40	11.00	2.93	48.36

Mean copper values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	16.32	3	3.91	4	8.37	1	1.90
M	**Grain**	3	9.12	4	3.57	4	19.16	1	3.07
U	**Grain**	3	17.28	4	4.52	4	14.83	1	3.07
L	**Straw**	3	2.81	3	2.16	4	2.34	1	2.07
M	**Straw**	3	2.91	4	3.35	4	2.59	1	1.50
U	**Straw**	3	2.27	4	2.53	4	2.53	1	1.27

Effect of soil properties
Copper was significantly correlated with Zn (r=0.50) (Table 1).

In plants, copper and zinc are related, as they are frequently absorbed into the root through common carrier sites (Moraghan and Mascagni 1991). Once inside the plant, the main interacting ion for copper is zinc, and it has been suggested that these two nutrients often compete for the same transport sites (Kochian 1991). At the physiological level, there is also an isoenzyme, "Cu-Zn-SOD", which contains both elements and which is mainly concentrated in the stroma of the chloroplast (Romheld and Marschner 1991). This isoenzyme is important for the detoxification of superoxide (O_3) radicals resulting from photosynthesis. The activity of this isoenzyme is reduced with deficiencies of either zinc or copper. The occurrence of both of these micronutrients as components of this isoenzyme may explain the positive correlation observed in this data set.

Effect of ecoregion

Copper was not found to differ significantly between any of the ecoregions for the canola, wheat and barley crops (Table 2). The forage samples did however differ significantly between ecoregions with the Mixed Grassland having the highest concentrations of this element. This differs from the findings of Pawluk and Bayrock (1969) who found that levels of copper in Alberta were considered at mid level for all of central and southern Alberta, including the Moist Mixed Grassland, Mixed Grassland, and the Boreal Transition ecoregions.

Effect of slope

There was no significant difference in copper levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Copper levels were higher in the grain samples for the canola, wheat, and barley crops (Table 4). Similarly, Garnett and Graham (2005) observed that the majority of copper measured in plant tissues when grown under adequate copper supply could be found in the grain component. As copper is phloem mobile within the plant system, it typically accumulates in areas of active growth. For example, during the vegetative growth stages, higher concentrations of copper are often found in plant roots rather than in the shoots (Kochian 1991). When grown under sufficient copper conditions, translocation from the leaves to the developing grain readily occurs at maturity (Loneragan 1975).

Diagnosing copper deficiencies

When deficient in plants, young leaves often become dark green, misshapen, and develop necrotic spotting (Salisbury and Ross 1992). Wheat, barley and oat crops are considered to be the most sensitive to deficiencies of copper, and as such, deficiencies have been observed on crops grown in mineral soils in both the Grey-Black and Black soil zones of Alberta (McKenzie 1992). Normal copper concentrations in plant tissues range from 5 to 20 mg/kg (Jones 1991, Wintz et al. 2001), with an average concentration of approximately 6 mg/kg (Jones 1991).

Typical copper concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998).

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<4	4 - 8	8
Cereals[2]			
Barley	<2.3	2.3 – 3.7	3.7
Wheat	<3	3 – 4.5	4.5
Oats	<1.7	1.7 - 2.5	2.5
Canola[3]	<1.7	1.7 – 2.7	2.7

1. Based on the upper 15 cm at 10% bloom
2. Whole plant prior to filling
3. At flowering

Iron (Fe)

Iron is an abundant element, and is essential for the normal function of higher plants. It is available to plants in two forms: Fe^{3+} and Fe^{2+} (Raven et al. 1999), although it is relatively immobile in the plant tissue once uptake has occurred. Iron plays an important role in metabolic processes, which include its involvement in the two to three enzymes necessary for catalyzing certain reactions in chlorophyll synthesis (i.e. iron acts as an electron carrier during photosynthesis), respiration, reduction of SO_4 and SO_3 and N_2 fixation (Romheld and Marschner 1991). It is also a component of the tricarboxylic acid (TCA) cycle, and is known to activate a number of other plant enzymes. In leaf tissue, the most stable and abundant form of iron is in the iron-protein complex, phytoferritin (Seckback 1982).

Iron Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	87.80	40.20	438.00	63.88	72.75
Straw	105	88.50	28.30	362.00	58.95	66.60
Forage	63	145.50	59.60	1370.00	165.30	113.61

Mean iron values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	79.02	3	86.82	4	63.65	1	112.03
M	**Grain**	3	100.22	4	110.65	4	63.18	1	64.00
U	**Grain**	3	92.38	4	117.24	4	85.98	1	58.97
L	**Straw**	3	82.96	3	48.03	4	112.73	1	56.43
M	**Straw**	3	128.41	4	52.96	4	117.65	1	57.63
U	**Straw**	3	87.58	4	53.32	4	135.72	1	53.10

Effect of soil properties

Iron was not significantly correlated with any soil properties or any of the elements included in this report (Table 1).

Effect of ecoregion

Iron was not found to differ significantly between the ecoregions for the canola or forage crops (Table 2). It was, however, found to differ significantly between the Fescue Grassland, Peace Lowland and Aspen Parkland for the barley crops, with the Peace Lowland having greater levels than the other two ecoregions. Soils in the Peace Lowland have higher iron concentrations than that of the Fescue Grassland and Aspen Parkland, which may help to explain these findings (Pawluk and Bayrock 1969).

Iron was also found to differ significantly between the Aspen Parkland, Mixed Grassland, and Moist Mixed Grassland for wheat crops. Wheat grown in the Moist Mixed Grassland

was found to have higher concentrations of iron than that of the Mixed Grassland or Aspen Parkland ecoregions. This does not coincide with findings of Pawluk and Bayrock (1969), who indicated that higher iron levels in the soil often occur in the Aspen Parkland.

Effect of slope

There was no significant difference in iron levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Although iron is considered to be an intermediately mobile micronutrient (Kochian 1991) its concentration was greater in the straw samples of wheat, but was found to be greater in the grain samples of canola (Table 4). No significant difference was found between iron concentrations in the straw and grain of the barley crop, although concentrations did tend to be greater in the straw portion of this crop. Approximately 80% of the total iron found in plants can be found in the plant chloroplast (Mengel and Kirkby 1987), which may explain the higher concentration of this element found in the straw material. In cereal grains and roots the iron content is considerably lower than that found in green plant tissue. Iron can be stored in the stroma of plastids, but can also be found in the xylem and phloem (Marschner 1995).

Diagnosing iron deficiencies

Symptomology of iron deficiency in plants includes interveinal chlorosis, beginning first on younger leaves, followed by the eventual chlorosis of the entire leaf (Salisbury and Ross 1992). In severe cases, the entire leaf may become white and develop necrotic lesions. Deficiency of this micronutrient is exacerbated under conditions of high pH and by the presence of bicarbonates in the soil. In Alberta, iron deficiencies have not yet been known to occur in field crops (McKenzie 1992).

Typical iron concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998).

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<20	20 - 30	30
Cereals[2]	<15	15 - 20	20
Canola[3]	<15	15 - 20	20

1. Based on the upper 15 cm at 10% bloom
2. Whole plant prior to filling
3. At flowering

Manganese (Mn)

Plant roots absorb manganese as the divalent cation Mn^{2+} (Welch et al. 1991). This essential micronutrient plays an important role in cell reduction-oxidation processes (Romheld and Marschner 1991; Marschner 1995), in addition to being essential for activating numerous plant enzymes. Perhaps the most well known role of manganese is its structural role in the chloroplast membrane system, where it is associated with the oxidation of water during the photosynthesis reactions (Romheld and Marschner 1991; Salisbury and Ross 1992).

Manganese Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	38.88	9.00	90.20	17.96	46.19
Straw	105	34.25	5.60	114.00	25.44	74.27
Forage	63	45.37	13.80	176.00	34.67	76.41

Mean manganese values (mg/kg) for each crop differentiated by plant tissue and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	16.84	3	38.83	4	58.77	1	57.00
M	**Grain**	3	16.30	4	41.60	4	47.88	1	49.63
U	**Grain**	3	14.41	4	41.86	4	46.39	1	48.97
L	**Straw**	3	25.49	3	14.14	4	65.67	1	57.27
M	**Straw**	3	23.94	4	18.91	4	45.07	1	73.77
U	**Straw**	3	20.51	4	18.44	4	39.92	1	63.43

Effect of soil properties

Manganese was not significantly correlated with any soil properties or any of the elements included in this report (Table 1).

Effect of ecoregion

Manganese concentration in canola was not found to differ among the Aspen Parkland, the Moist Mixed Grassland, or the Peace Lowland ecoregions (Table 2). A significant difference did occur, however, between ecoregions for barley, wheat and forage crops. The Peace Lowland ecoregion was found to have higher manganese levels than either the Fescue Grassland or Aspen Parkland ecoregions for barley. This is not explained by the findings of Pawluk and Bayrock (1969), who identified the southern portion of the province as having higher levels of manganese than the Northern regions. This is also in contrast to our findings for the forage samples, where the highest concentrations of manganese occurred in the Boreal Transition and the lowest in the southern portions of the province, including the Moist Mixed and Mixed Grasslands. Both the Aspen

Parkland and the Moist Mixed Grassland had higher levels of manganese in wheat than did the Mixed Grassland ecoregion in the southeast.

Effect of slope

There was no significant difference in manganese levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Manganese was found at significantly higher concentrations in the grain samples of canola than in the straw component (Table 4). In contrast, higher levels of manganese were reported in the barley straw samples than in the grain. The concentration of manganese did not differ significantly between the grain and straw samples for the wheat crops, although the grain samples did tend to have slightly higher levels of manganese than that measured in the straw. Manganese is considered to be an intermediately mobile micronutrient (Kochian 1991), which due to its phloem mobility, may account for its presence within the grain component. Under adequate conditions, manganese is also found at higher concentrations in root tissues, rather than the leaves, again a result of its high phloem mobility. Even under manganese deficiency, seeds are often supplied with adequate levels of this micronutrient (at the expense of other parts of the crop) via the phloem transport system.

Diagnosing manganese deficiencies

Manganese deficiency is not common, and is often referred to as "gray speck" in oats (the crop in which deficiencies are most susceptible, McKenzie 1992), "marsh-spot" in peas or "speckled yellows" in sugar beets (Salisbury and Ross 1992). As with most micronutrient deficiencies, it is characterized by interveinal chlorosis of both young and old plant tissues, although this symptomology is somewhat species-dependant. Following chlorosis, and depending on the severity of the deficiency in soil, necrotic lesions may develop throughout the plant tissue. The manganese content of plants ranges widely from 31 to 100 mg/kg (Knezek and Ellis 1980), with average concentrations of approximately 50 mg/kg (Jones 1991).

Typical manganese concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998).

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<15	15 - 25	25
Cereals[2]	<10	10 - 15	15
Canola[3]	<10	10 - 15	15

[1.] Based on the upper 15 cm at 10% bloom

[2.] Whole plant prior to filling

[3.] At flowering

Molybdenum (Mo)

At the beginning of the century molybdenum was detected in plant material, however its significance as a micronutrient was not fully discovered until much later (Fleming 1980). Among all the micronutrients, molybdenum, along with nickel are the least required by plants, particularly in some grain crops such as wheat, barley, and oats (Jones 1991). As such, little is known about its exact function(s) in the plant, and deficiencies are rare with the exception of some plants grown in Australia and certain regions of the eastern USA. Plants take up molybdenum as MoO_4^{-2} (Raven et al. 1999), where its function appears to be related to electron transfer reactions (Romheld and Marschner 1991). It is also important for enzyme complexes, particularly the nitrate reductase enzyme that is responsible for the conversion of nitrate to nitrite (Fleming 1980; Jenkins and Jones 1980; Salisbury and Ross 1992).

Molybdenum Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	1.02	0.50	30.20	2.89	283.19
Straw	105	0.66	0.50	5.20	0.54	80.97
Forage	63	1.53	0.50	3.70	0.74	48.04

Mean molybdenum values (mg/kg) for each crop differentiated by plant tissue and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	0.69	3	0.81	4	0.84	1	0.50
M	**Grain**	3	0.67	4	3.19	4	0.55	1	0.50
U	**Grain**	3	1.02	4	0.82	4	0.76	1	0.57
L	**Straw**	3	0.50	3	0.89	4	0.89	1	0.77
M	**Straw**	3	0.53	4	0.91	4	0.55	1	0.50
U	**Straw**	3	0.54	4	0.58	4	0.56	1	0.50

Effect of soil properties

Molybdenum was not significantly correlated with any soil properties or any of the elements included in this report (Table 1).

Effect of ecoregion

Molybdenum did not differ significantly between ecoregions for barley, wheat, or canola (Table 2). Significantly higher levels of molybdenum were found, in the Mixed Grassland ecoregion for forage crops. In contrast to our findings, higher levels of molybdenum have been observed to occur in soils located in the northern regions of the province, with the levels remaining fairly consistent at 1 ppm throughout the rest of the province (Pawluk and Bayrock 1969).

Effect of slope

There was no significant difference in molybdenum levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Molybdenum concentrations were significantly higher in the barley straw samples than in the grain (Table 4). Although there was no significant difference between molybdenum concentrations in the grain and straw samples for the canola and wheat crops, molybdenum concentrations tended to be higher in those grain samples. Molybdenum allocation among the various plant organs is known to vary considerably both between plant species and within genotypes of the same species (Marschner 1995). It has been found that accumulation of molybdenum in the root nodules of legume species, when grown under limiting conditions leads to a lower content of molybdenum in the shoots and seeds (Marschner 1995). In seeds, molybdenum content is highly variable among plant species, although a high concentration appears to ensure proper growth of young seedlings and ultimately high grain yields (Marschner 1995). In their study of winter wheat cultivars, Yu et al. (2002) found that most molybdenum accumulated in the shoots of plants and that even under sufficient conditions, concentrations in both the spikes and seeds remained very low. This agrees with our findings for barley, where the straw concentration was higher than that of the grain samples. Although not statistically significant, results indicate that the concentration of molybdenum was higher in grain for the wheat samples.

Diagnosing molybdenum deficiencies

Molybdenum deficiencies have not been diagnosed in field crops in Alberta (McKenzie 1992). When molybdenum deficiency does occur however, it is characterized by interveinal chlorosis in older and mid-stem leaves, and depending on its severity, this may progress up the plant to include younger and younger plant tissues (Salisbury and Ross 1992).

Typical molybdenum concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998)

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<0.5	0.5 – 1.0	1.0
Cereals[2]	<0.01	0.01 – 0.02	0.02
Canola[3]	-	-	-

1. Based on the upper 15 cm at 10% bloom
2. Whole plant prior to filling
3. At flowering

Nickel (Ni)

Historically, the focus on nickel centered on its toxic effects on plant growth (Asher 1991), as until recently its beneficial role in plants was widely unknown (Evans and Solberg 1998). Research has now demonstrated that plants utilize small amounts of Ni^{2+} as a component of the urease enzyme responsible for the hydrolysis of urea (nitrogen) to CO_2 and NH_4 (Salisbury and Ross 1992; Marschner 1995). It has also been discovered that nickel is both a requirement for the process of symbiotic fixation of nitrogen (Munson and Nelson 1990) and that low concentrations of this micronutrient in the plant tissue have beneficial effects on plant growth (Asher 1991). For example, it has been found to be essential for the grain viability in barley (Asher 1991) and may be responsible for stimulating the germination and growth of various other crop species (Marschner 1995).
When exposed to nickel deficiencies, plants have been known to accumulate high levels of urea in their leaf tips, which essentially burn the leaf tissue creating necrotic leaf edges (Salisbury and Ross 1992).

Nickel Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	0.76	0.15	3.32	0.66	87.46
Straw	105	0.33	0.10	0.96	0.19	56.92
Forage	63	1.42	0.23	3.72	0.78	55.02

Mean nickel values (mg/kg) for each of crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	0.27	3	1.09	4	0.53	1	1.24
M	**Grain**	3	0.31	4	0.92	4	0.52	1	2.27
U	**Grain**	3	0.28	4	1.17	4	0.50	1	2.64
L	**Straw**	3	0.26	3	0.40	4	0.31	1	0.18
M	**Straw**	3	0.27	4	0.40	4	0.36	1	0.27
U	**Straw**	3	0.23	4	0.40	4	0.34	1	0.28

Effect of soil properties
Nickel was significantly correlated with boron (r= 0.43) (Table 1). A review of the literature was not conclusive in indicating any known relationship between nickel and boron in plants.

Effect of ecoregion
Nickel was not found to differ significantly among ecoregions for the wheat or forage crops (Table 2). In barley, however, nickel concentrations were found to be significantly greater in the Peace Lowland region than in either the Fescue Grassland or Aspen

Parkland ecoregion. Nickel levels in canola were also found to be significantly greater in the Peace Lowland when compared to the Aspen Parkland, but in general were similar to those measured in the Moist Mixed Grassland.

Effect of slope

There was no significant difference in nickel levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Levels of nickel were significantly greater in the grain samples than in the straw samples for both the wheat and canola crops (Table 4) and, although not significant, this trend also appeared in barley. Nickel is both phloem and xylem mobile in plants, and as such, in some plant species it is preferentially located in the seeds and along leaf edges (Marschner 1995; Kochian 1991). For example, Cataldo et al. (1978) described the transfer of considerable amounts of nickel to the seeds and fruits of plants, but only after the initial uptake of this element was complete.

Diagnosing nickel deficiencies

There is no clear evidence for deficiencies of nickel in soil-grown plants, and most of the concern over nickel is focused on its toxicity (Marschner 1995). Oats is considered to be a sensitive crop with respect to nickel toxicities, with symptoms resembling that of iron deficiencies (Vergnano and Hunter 1952). Fortunately, most soils contain only small quantities of this element (<100 ppm), with the exception of some soils based on ultrasonic igneous rocks located in the coast mountain ranges of the Pacific Northwest.

In general, the nickel content of plant vegetative organs ranges from 1 to 10 ug/g (Marschner 1995), with critical deficiency concentrations of less than 1 ug/g, for example barley at 0.1 ug/g. When grain concentrations are less than 0.1 mg/kg, research has indicated that the germinability of the seed decreases linearly with decreasing nickel concentrations (Asher 1991).

Selenium (Se)

Similar to nickel, much of the focus on selenium is concerned with its accumulation in plant species, and its subsequent toxic effects on livestock/human health (Fleming 1980). Although its physiological response varies widely among plants (Terry et al. 2000), it has been discovered that it is beneficial for certain plants in order to carry out the symbiotic fixation of nitrogen (Munson and Nelson 1990). Most agricultural plants are considered to be non-accumulators of selenium, however there are plants, which are capable of assimilating large quantities of this element. These species include plants from the genera *Astragalus* (Vetch) *Stanleya (*wild flowers of the *Brassica* family*), Haplopappus (*Aster family*)*, *Xylorhiza (*Aster family*)*, *Atriplex* (saltbrush) and *Grindelia (*Herb family*)*(Fleming 1980; Welch et al. 1991; Salisbury and Ross 1992).
In terms of plant toxicity, excess selenium can lead to stunting and chlorosis of new leaves, as it tends to be concentrated in the actively growing parts of plants and in the newly formed seed (Mengel and Kirkby 1987). Under neutral and acid soils, selenium is relatively unavailable owing to its ability to form ferric-selenite and organic complexes. Selenate (SeO_4^{-2}), the form of selenium taken up by plants (Marschner 1995), occurs only under well-aerated alkaline conditions, as what might be expected in arid environments. Under these environments, selenate may accumulate to relatively high concentrations in plant tissues (up to 0.5% by weight, Salisbury and Ross 1992). As eluded to earlier, the largest concern with high concentrations of selenium is the development of a fatal sickness in livestock known as "alkali disease" or blind staggers (Mengel and Kirkby 1987; Salisbury and Ross 1992). This disease has been identified as a potential concern to livestock producers in the Great Plains of the USA.

Selenium Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	0.59	0.20	3.40	0.40	68.18
Straw	105	0.48	0.20	2.30	0.34	71.19
Forage	63	0.51	0.20	1.60	0.33	65.01

Mean selenium values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	0.50	3	0.71	4	0.48	1	0.30
M	**Grain**	3	0.67	4	0.66	4	0.73	1	0.37
U	**Grain**	3	0.69	4	0.55	4	0.58	1	0.27
L	**Straw**	3	0.43	3	0.28	4	0.30	1	0.40
M	**Straw**	3	0.48	4	0.56	4	0.82	1	0.47
U	**Straw**	3	0.46	4	0.55	4	0.49	1	0.23

Effect of soil properties
Selenium was not significantly correlated with any soil properties or any of the elements included in this report (Table 1).

Effect of ecoregion
Selenium levels were not found to differ significantly between ecoregions for the barley, canola or forage crops (Table 2). Selenium levels were, however, significantly greater in the Mixed Grassland ecoregion for wheat crops, than what was measured in the Aspen Parkland.

Effect of slope
There was no significant difference in selenium levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw
Selenium levels were found to be significantly greater in the grain samples of barley, and, although not significantly so, tended to be greater in the grain of both canola and wheat crops (Table 4). As excess selenium tends to be concentrated within both the growing points (new leaves/stems) and the seed of plants (Mengel and Kirkby 1987), this may aide in explaining the higher concentrations of selenium measured in grain samples for all crops studied. It is important to note that the uptake and accumulation of selenium in plant shoots varies greatly among plant species, as does their capacity to tolerate these high levels (Marschner 1995).

Diagnosing selenium deficiencies
Historically, the primary concern over selenium levels has been associated with its accumulation in plants, and subsequent toxicity in livestock. As such, deficiency information in plants is quite limited (Marschner 1995). Research indicates that selenium accumulators can contain >50 mg/kg, whereas grasses and crop plants typically contain well below <10 mg/kg (Welch et al. 1991).

Silicon (Si)

Silicon is the second most abundant element in the Earth's crust and is known to occur in almost all minerals (Mengel and Kirkby 1987). Although numerous benefits of silicon in plant species have been reported, its essentiality in plants has only been established in a few species (Marschner 1995). Benefits to agricultural plants include: increased resistance to fungal diseases, Mn, Fe, and Al toxicity and pest attacks, increased phosphorus availability, and a decrease in transpiration rates (Asher 1991; Marschner 1995). The deposition of silicon in cell walls can also stimulate growth and yield by increasing overall stalk strength and hence, lodging resistance (Marschner 1995). Large amounts of this element are deposited in the cell walls of the xylem, which not only maintains cell wall rigidity, but also increases elasticity of the cell walls during extension growth. Furthermore, this element is also deposited within the epidermal layers of leaf cells, where they assist in maintaining leaf strength. Research also exists for silicon's role in helping plants manage the distribution of internal manganese levels (Mengel and Kirkby 1987).

Accumulators of the element include Horsetail (*Equisetum arvense*) and members of the Gramineae (grass) species, particularly rice. Dryland species of Gramineae, which include most cereal crops, are considered to be intermediate accumulators of this element (Asher 1991; Marschner 1995). Although plant species vary widely in their uptake of silicon, they all utilize this element as silicic acid or $Si(OH)_4$. Not surprisingly, when silicon is deficient, which is highly unlikely owing to its ample presence in the Earth's crust, a loss of stem strength and subsequent crop lodging often occurs (Salisbury and Ross 1992). At the other extreme, where excessive silicon has accumulated in the plant, crops may become somewhat unpalatable to livestock, and under certain extreme conditions, excessive silicon may lead to the formation of kidney stones.

Silicon Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	70.34	5.00	268.00	70.09	99.65
Straw	105	365.31	32.30	818.00	232.69	63.70
Forage	63	229.03	26.10	680.00	179.92	78.56

Mean silicon values (mg/kg) for each crop differentiated by plant tissue part and landscape positions. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	Grain	3	125.67	3	24.12	4	20.03	1	178.33
M	Grain	3	128.29	4	38.03	4	18.34	1	234.00
U	Grain	3	124.79	4	49.08	4	23.08	1	246.67
L	Straw	3	548.11	3	57.68	4	478.17	1	359.33
M	Straw	3	549.56	4	68.70	4	500.42	1	347.00
U	Straw	3	537.78	4	71.80	4	513.58	1	469.33

Effect of soil properties

Silicon was significantly correlated with Cl (r=0.47), Zn (r=-0.43), and CEC (r=0.43) (Table 1).

Silicon's relation to chlorine has been discussed above, under the section devoted to that micronutrient. With respect to zinc, however, a negative correlation exists between these two micronutrients. A possible explanation for this observation may be associated with the presence of silicates that often decrease the solubility of aluminum and other heavy metals, including zinc, all the while increasing the availability of phosphorus (Asher 1991). Thus, silicon supply increases the physiological availability of zinc in the plants by an unknown mechanism (Marschner 1995).

CEC refers to the cation exchange capacity of soil, and is a measure of the total amount of exchangeable cations that a soil is able to adsorb (Brady 1990). Although present in all soil types, CEC is particularly high in organic soils and soils that are composed primarily of clay materials. A positive correlation between CEC and silicon may also be the result of the presence silicate clays at the Benchmark Sites. These clays are composed of alternating layers of silica (SiO_2) and aluminum (Brady 1990; Conklin 2002), thus the occurrence of silicon in the plant tissue may reflect its availability in the clay soil material.

Effect of ecoregion

Silicon levels were found to differ significantly between ecoregions for all crops studied at the Benchmark Sites (Table 2). Silicon levels in barley were significantly greater in the Fescue Grassland and Peace Lowland than those measured in the Aspen. For wheat, the greatest silicon levels were found in the Mixed Grassland, which differed significantly from both the Aspen Parkland and Moist Mixed Grassland. Silicon concentrations were significantly greater in canola for the Moist Mixed Grassland than the Aspen Parkland. The forage results indicated a significantly greater level of silicon in the Boreal Transition and the Moist Mixed Grassland.

Effect of slope

There was no significant difference in silicon levels between the upper, mid and lower slope positions in any of the sites included in this study (Table 3).

Grain vs. Straw

Not surprisingly, silicon concentrations were significantly greater in the straw samples for barley, wheat and canola crops (Table 4) owing to its important role in the structural strength of plant stems (Marschner 1995).

Diagnosing silicon deficiencies

The essentiality of silicon for higher plants is difficult to prove and there is no data available on critical deficiency concentrations within plants (Marschner 1995). For silicon accumulating plants such as rice and sugarcane the deficiency symptoms would include leaf necrosis and wilting of plants owing to a lack of structural strength.

Zinc (Zn)

Plants primarily utilize zinc as a divalent cation (Zn^{2+}), likely derived from zinc chelates found in the soil (Salisbury and Ross 1992; Marschner 1995). Zinc is an essential micronutrient necessary for sugar regulation and assorted enzymatic activity associated with plant growth (Evans and Solberg 1998). It is quite prevalent in plant tissues, as it has been identified in over 80 different enzymes, where it plays both a vital catalytic role and acts as a structural component in numerous proteins (Romheld and Marschner 1991; Salisbury and Ross 1992; Hall and Williams 2003).

Zinc Results from the AESA Soil Quality Benchmark Sites

Plant Tissue	N=	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)	SD	CV (%)
Grain	105	43.10	21.20	84.10	10.14	23.54
Straw	105	13.39	3.40	46.60	7.56	56.45
Forage	63	19.24	4.50	57.20	8.57	44.56

Mean zinc values (mg/kg) for each crop differentiated by plant tissue part and landscape position. Note that mg/kg = ppm.

Slope	Type	Barley		Canola		Wheat		Oats	
		N	Mean	N	Mean	N	Mean	N	Measure
L	**Grain**	3	51.14	3	48.78	4	49.23	1	31.23
M	**Grain**	3	42.79	4	40.28	4	45.97	1	30.67
U	**Grain**	3	47.69	4	40.32	4	36.14	1	27.53
L	**Straw**	3	22.49	3	12.54	4	15.17	1	23.60
M	**Straw**	3	16.24	4	8.03	4	12.13	1	11.47
U	**Straw**	3	18.90	4	8.03	4	10.31	1	8.40

Effect of soil properties

Zinc was significantly correlated with Si (r= -0.43), Cl (r=-0.41), Cu (r=0.50), and sand (r=-0.49) (Table 1).

The relationship between Zn and Si, Cl and Cu has been previously discussed under each of the respective micronutrients. At the Benchmark Sites, however, zinc and sand were negatively correlated in this research. With an increase in the sand content of the soil, CEC capacity is lowered, and there would be less exchangeable zinc available to for plant uptake. As such, the possibility for zinc to have been leached from the soil is also greater, leading to a negative correlation between these two parameters. Alternatively, the limited sample size may in part account for the negative relationship.

Effect of ecoregion

No significant differences in zinc levels were found between ecoregions for wheat, canola or forage crops (Table 2). For barley, however, zinc levels were significantly greater in the Peace Lowland, than in the Fescue Grassland or Aspen Parkland. This coincides with the findings of Pawluk and Bayrock (1969), who identified that the soils

of Northwestern Alberta, including those of the Peace Lowland ecoregion, typically have the greatest zinc concentrations of the province.

Effect of slope

With the exception of barley, there were no differences among slope positions for any of the crop samples harvested from the Benchmark Sites (Table 3). For the barley samples, the lower slope position was found to have a greater concentration of zinc within the plant tissue (mean=36.82), which was significantly different from that measured in the mid slope position (mean=29.52).

Higher levels of erosion from the upper slope position lead to an increase in the silt, clay and organic matter composition of the lower slope positions. As zinc is strongly correlated with clay it tends to be found in landscape positions with higher clay composition. This potentially explains the higher concentration of Zn in the barley samples from the lower slope position.

Grain vs. Straw

Zinc levels were found to be significantly greater in the grain samples for barley, canola, and wheat (Table 4). Similarly, Dvorak et al. (2003) in studying a wheat crop found that zinc was transported primarily to and accumulated in, the grain produced by the plant, whereas straw concentrations were always lower. In contrast, Mengel and Kirkby (1987) describe zinc as having low mobility within plants and have found that it accumulated in root tissues.

Diagnosing zinc deficiencies

In terms of its potential deficiency, symptoms such as “little leaf” and “rosette” of fruit trees have been identified when zinc levels are low. These symptoms appear as a reduction in the growth of both young leaves and stem internodes, resulting from zinc’s requirement in growth hormones such as indoleacetic acid. In other crops, such as corn or beans, interveinal chlorosis is evident, as is puckering and distortion of the leaf margins. If zinc deficiencies do occur, however, they typically occur under cool and wet conditions encountered in spring (McKenzie 1992). In general, zinc concentrations can range widely from 30 to 100 ug/g (Wintz et al. 2001). In Alberta, cornfields grown in the southern part of the province have been suspect for zinc deficiencies, and field beans grown in the same region, have responded to applications of this micronutrient.

Typical zinc concentrations (ppm) for alfalfa, cereals and canola in the Canadian prairies (McKenzie 1992, 1998)

Crop	Low	Marginal	Sufficient
Alfalfa[1]	<12	12 - 20	20
Cereals[2]	<10	10 - 15	15
Canola[3]	<12	12 - 15	15

1. Based on the upper 15 cm at 10% bloom
2. Whole plant prior to filling
3. At flowering

Summary

Results of the micronutrient analysis of crops harvested from the AESA Soil Quality Benchmark Sites revealed a great deal of variability, which was not always explainable based on the current data set. It is important to note that samples were collected after several years (2001 - 2003) of dry conditions throughout much of Alberta, and it is known and generally accepted that climate extremes have a detrimental effect on the availability of many plant [micro]nutrients. Furthermore, there are a number of other potential explanations for differing levels of mineral nutrients in plant tissues (Sawyer 1994) that were beyond the scope of this research. These include factors such as the excessive loading of other nutrients, low temperatures, salt damage, root rot, disease, insect damage, soil compaction, drought and/or flooding. All of these factors need to be considered when assessing the true tissue nutrient concentration of crops.

Twenty-one correlations ($r \geq \pm 0.4$) between micronutrient concentrations and selected soil properties were identified in this study. In general, the results indicate that various soil properties, ecoregions (climate/soil) and partitioning patterns between the grain and the vegetative tissues were affected. In comparison, landscape position did not have an effect on micronutrient concentrations, with upper, mid and lower slope positions having similar values at each Benchmark Site across Alberta.

When possible, a value for assessing whether the crop was deficient in any of the micronutrients analyzed was presented based on previous research conducted by Mckenzie (1992, 1998). Results indicated that there were no cases where micronutrients were deficient at any of the seventeen Benchmark Sites sampled, and presumably, this would be the case for much of Alberta, owing to the relatively young age of its soil resource. With regard to potential micronutrient toxicities, results also indicate that this does not appear to be a problem at the studied locations, although other research has indicated that selenium may pose a problem in the cattle producing areas of the Great Plains.

The current study was undertaken in response to a report written previously which outlined the micronutrient and trace element status of soils on the AESA Soil Quality Benchmark Sites (Penney 2004). Results of the 2002 soil micronutrient study identified deficiencies and/or concerns at several of the Benchmark locations, specifically with respect to the concentration of Ni, Si, Cr, Cd and Se. Plant tissue analysis at the Benchmark Sites was recommended in order to determine if deficient levels also occurred in plant tissues as a result of low soil test values. As noted above, micronutrient and trace element concentrations were within an acceptable range for all of the crops tested, regardless of their location both within the landscape (i.e., catena) and across the province.

In conclusion, it is important to note that as plant tissue samples were only available from the 2003 harvest year, additional sampling to strengthen and confirm these observations is required to definitively identify whether or not Alberta soils are deficient in any of the micronutrients and trace elements tested. Furthermore, caution need be exercised in

interpreting the vegetative tissue micronutrient concentrations, as the harvest technique employed in this research necessarily required the removal and homogenization of the entire plant, following the removal of grain (owing to economic and physical work-load constraints). Depending on nutrient, this may not be the recommended procedure for all of the elements analyzed. As such, micronutrient concentrations in the vegetative plant parts may be somewhat lower than what would be expected earlier during the growing season, owing to the translocation of minerals to the reproductive structures (grain/seeds).

References

[AOAC] Official Methods of the Association of Analytical Chemists: Official Method 985.01 *in* Official Methods of Analysis of AOAC International. 16 edition. Volume 1, Chapter 3 and 4.

Asghari, M. and R. G. Hanson. 1984. Climate, management, and N effect on corn leaf N, yield, and grain N. Agron. J. 76:911-946.

Asher, C. J. 1991. Beneficial elements, functional nutrients, and possible new essential elements. *In*: Mortvedt, J.J., Cox, F.R., Shuman, L.M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 703-723. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Bell, R. W. 1997. Diagnosis and prediction of boron deficiency for plant production. Plant Soil 193: 149-168.

Brady, N. C. 1990. The Nature and Properties of Soils: Tenth edition. Macmillan Publishing Company, New York. 621 pp.

Cannon, K. R. 2002. Alberta Benchmark Site Selection and Sampling Protocols. Prepared for the AESA Soil Quality Resource Monitoring Program. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development, Edmonton, AB. 43 pp.

Cannon, K. R. and L. Leskiw. 1999. Soil Quality Benchmarks in Alberta. *In:* Proceedings of the 36th Annual Alberta Soil Science Workshop. February 16-18, 1999. Calgary, AB. pp181-183.

Cataldo, D. A., Garland, T. R., Wildung, R. E., and H. Drucker. 1978. Nickel in plants. II. Distribution and chemical form in soybean plants. Plant. Physiol. 62: 566-570.

Conklin Jr., A. R. 2002. Soil Clays. (www.aehsmag.com/issues/2002/june/soilclays.htm). Accessed August 1, 2005.

Dvorak, P., Tlustos, P., Szakova, J., Cerny, J., and J. Balik. 2003. Distribution of soil fractions of zinc and its uptake by potatoes, maize, wheat and barley after soil amendment by sludge and inorganic Zn salt. Plant Soil Environ. 49: 203-212.

Evans, I. R., and E. Solberg. 1998. Minerals for plants, animals, and man. Agri-Facts (Agdex 531-3). Alberta Agriculture Food and Rural Development.

Fixen, P. E., Buchenau, G. W., Gelderman, R. H., Schumacher, T. E., Gerwing, J.R., Cholick, F. A., and B. G. Farber. 1986. Influence of soil and applied chloride on several wheat parameters. Agron. J. 50:736-740.

Fleming, G. A. 1980. Essential micronutrients I: boron and molybdenum. *In*: Davies, B.E. (ed.). Applied Soil Trace Elements. pp. 155-197. John Wiley & Sons. Great Britain.

Garnett, T. P. and R. D. Graham. 2005. Distribution and remobilization of iron and copper in wheat. Ann. Bot. 95: 817-826.

Graham, R. D. and M. J. Webb. 1991. Micronutrients and disease resistance and tolerance in plants. *In*: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 329-370. Soil Science Society of America, Inc. Madison, Wisconsin, USA

Hall, J. L., and L. E. Williams. 2003. Transition metal transporters in plants. J. Exp. Bot. 54: 2601-2613.

Hart, J. J., Welch, R. M., Norvell, W. A., Sullivan, L. A., and L. V. Kochian. 1998. Characterization of cadmium binding, uptake, and translocation in intact seedlings of bread and durum wheat cultivars. Plant Phys. 116: 1413-1420.

Jenkins, D. A., and R.G.W. Jones. 1980. Trace elements in rocks, soils, plants and animals: introduction. *In*: Davies, B. E. (ed.). Applied Soil Trace Elements. pp. 1-20. John Wiley & Sons. Great Britain.

Jones Jr., J. B. 1991. Plant tissue analysis in micronutrients. *In*: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 477-521. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Knezek, B. D. and B. G. Ellis. 1980. Essential micronutrients IV: copper, iron, manganese, and zinc. *In*: Davies, B. E. (ed.). Applied Soil Trace Elements. pp. 259-286. John Wiley & Sons. Great Britain.

Kochian, L. V. 1991. Mechanism of micronutrient uptake and translocation in plants. In: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 229-285. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Leskiw, L. A., Yarmuch, M. S., Waterman, L. P., and J. J. Sansom. 2000. Baseline soil physical and chemical properties of forty-three soil quality benchmark sites in Alberta. Can-Ag Enterprises Ltd. Prepared for the AESA Soil Quality Resource

Monitoring Program. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development. Edmonton, AB. 174 pp.

Loneragan, J. F. 1975. The availability and adsorption of trace elements in soil-plant systems and their relation to movement and concentrations of trace elements in plants. *In:* D.J.D. Nicholas and A. R. Egan (eds). Trace Elements in Soil-Plant-Animal Systems. pp. 109-134. Academic Press, London.

Mankin K. R. and R. P. Fynn. 1996. Modeling individual nutrient uptake by plants. Agric. Systems. 50:101-114.

Marschner, H. 1995. Functions of mineral nutrients: micronutrients. Chapter 9. *In:* Mineral Nutrition of Higher Plants. Academic Press Inc. San Diego, CA.

McKenzie, R. H. 1992. Micronutrient requirements of crops. Agri-Facts (Agdex 531-1). Alberta Agriculture Food and Rural Development.

McKenzie, R. H. 1998. Crop nutrition and fertilizer requirements. Agri-Facts (Agdex 540-1). Alberta Agriculture Food and Rural Development.

Mengel, K. and Kirkby, E. A. 1987. Principles of Plant Nutrition 4th Edition. International Potash Institute. Worblaufen-Bern/Switzerland. 687 pp.

Moraghan, J. T., and Mascagni Jr., H. J. Environmental and soil factors affecting micronutrient deficiencies and toxicities. Chapter 11. *In:* Mortvedt, J. J., Cox, F. R., Shuman, L. M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 371-411. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Munson, R. D. and W. L. Nelson. 1990. Principles and practices in plant analysis. *In*: Westerman, R. L. (ed). 1990. Soil Testing and Plant Analysis: Third Edition. Number 3 in the Soil Science Society of America Book Series. pp.359-387. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Norvell, W. A., Wu, J., Hopkins, D. G., and R. M. Welch. 2000. Association of cadmium in durum wheat grain with soil chloride and chelate-extractable soil cadmium. Soil Sci. Soc. Am. J. 64: 2162-2168.

Novoa, R. and R. S. Loomis. 1981. Nitrogen and plant production. Plant Soil. 58:177-204.

Nyborg, M. and P. B. Hoyt. 1970. Boron deficiency in turnip rape growth on gray wooded soils. Can. J. Soil Sci. 50:87-88.

Olek J. and T. Filipek. 2005. Content and uptake of cadmium and lead by spring barley under conditions of sewage applications

(http://natres.psu.ac.th/Link/SoilCongress/bdd/symp25/2587-t.pdf). Accessed August 1, 2005.

Pawluk, S. and Bayrock, L. A. 1969. Some characteristics and physical properties of Alberta tills. Research Council of Alberta Bulletin 26. Research Council of Alberta. Edmonton, AB.

Penny, D. 2004. The micronutrient and trace element status of forty-three soil quality benchmark sites in Alberta. Prepared for the AESA Soil Quality Monitoring Program. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development. Edmonton, AB. 81 pp.

Raven, P. H., Evert, R. F., and S. E. Eichhorn. 1999. Biology of plants: sixth edition. W.H. Freeman and Company Worth Publishers. 1999. New York, NY. 944 pp.

Risser, J. A. and D. E. Baker. 1990. Testing soils for toxic metals. *In:* Westerman, R.L. (ed). Soil Testing and Plant Analysis: Third Edition. Number 3 in the Soil Science Society of America Book Series. pp.275-293. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Robb, D. A. and W. S. Pierpont (eds.). 1983. Metals and micronutrients. Uptake and utilization by plants. Academic Press, New York.

Romheld, V. and H. Marschner. 1991. Function of micronutrients in plants. *In*: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and Welch, R. M. (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 297-328. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

[SAS] Statistical Analysis Systems. 1994. SAS User's Guide: Statistics. 6th ed. Cary, NC: Statistical Analysis Systems Institute.

Sawyer, J. E. 1994. Concepts and variable rate technology with consideration for fertilizer application. J. Prod. Agric. 7:195-201.

Seckback, J. 1982. Ferreting out the secrets of plant ferretin: A review. J. Plant Nutrition 5: 369-394.

Salisbury, F. B. and C. W. Ross. 1992. Plant Physiology 4th Edition. Wadsworth Publishing Company, Belmont CA. 682 pp.

Solberg, E., Evans, I. R., and D. Penney. 1999. Copper deficiency: diagnosis and correction. Agri-Facts (Agdex 532-3). Alberta Agriculture Food and Rural Development.

Terry, N., Zayed, A. M., de Souza, M. P., and A. S. Tarun. 2000. Selenium in higher plants. Ann. Rev. Plant Phys. Plant Mol. Biol. 51: 401-432.

Tisdale, S. L., Nelson, W. L., Beaton, J. D, and J. L. Havlin. 1993. Soil Fertility and Fertilizers. Macmillan Publishing Cmpy. New York

Traylor Chemical and Supply Company Incorporated. (http://www.traylorchemical.com/faqs_ph.htm). Accessed July 19, 2005.

Vergnano, O. and J. G. Hunter. 1952. Nickel and cobalt toxicities in oat plants. Ann. Bot. 17: 317-328.

Welch, R. M., Allaway, W. H., House, W. A., and J. Kubota. 1991. Geographic distribution of trace element problems. *In*: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and R. M. Welch (eds). Micronutrients in Agriculture: Second Edition. Number 4 in the Soil Science Society of America Book Series. pp. 31-57. Soil Science Society of America, Inc. Madison, Wisconsin, USA.

White, P. J. and M. R. Broadley. 2001. Chloride in soils and its uptake and movement within the plant: a review. Ann. Bot. 88: 967-988.

Wintz, H., Fox, T., and C. Vulpe. 2001. Responses of plants to iron, zinc and copper deficiencies. Biochem. Soc. Trans. 30: 766-768.

Yu, M., Hu, C., and Y. Wang. 2002. Molybdenum efficiency in winter wheat cultivars as related to molybdenum uptake and distribution. Plant Soil 245: 287-293.

Appendices

Appendix 1. Micronutrient values for 17 benchmark sites

Appendix 2. Calculated mean, max, min and standard deviation of pH_w and pH_c for all sites

Appendix 2.1. Calculated mean, max, min and standard deviation of pH_w and pH_c for all ecoregions

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
588	PL	U	1	3	Grain	Canola	0.05	0.74	1	111	0.08	15.7	2.2	154	37.9	0.7	37.9
588		U	2	3	Grain	Canola	0.05	0.64	0.6	49.5	0.1	15.4	2.7	131	38.5	0.8	51
588		U	3	3	Grain	Canola	0.05	0.68	0.8	97.7	0.08	13.7	2.6	191	38.5	0.7	37.8
588	PL	U	1	3	Straw	Canola	0.11	0.21	0.5	69.4	0.16	30.1	3.6	73.5	16.2	0.5	8.1
588		U	2	3	Straw	Canola	0.1	0.16	0.3	72.4	0.19	29.4	2.1	67.4	16.8	0.8	8.1
588		U	3	3	Straw	Canola	0.09	0.2	0.4	92.3	0.17	28	2.7	88.9	16	0.5	6.3
588	PL	M	1	3	Grain	Canola	0.05	0.69	0.9	127	0.11	13.9	4.1	309	41.6	1	50.6
588		M	2	3	Grain	Canola	0.04	0.53	0.6	57.2	0.1	15.4	2.4	144	37.1	0.8	49.6
588		M	3	3	Grain	Canola	0.07	0.65	0.2	91.3	0.1	14.6	2.4	225	38.5	0.6	45.1
588	PL	M	1	3	Straw	Canola	0.1	0.21	0.6	84.3	0.12	27.7	2.4	110	17.2	1.5	8.7
588		M	2	3	Straw	Canola	0.1	0.18	0.3	65.4	0.11	33.5	2.5	74.5	16.2	2.3	9.3
588		M	3	3	Straw	Canola	0.14	0.23	0.7	72.5	0.11	32.4	2.9	67.7	14.8	2.1	11.3
588	PL	L	1	3	Grain	Canola	0.09	3.32	0.4	62.4	0.1	13.6	2.9	156	28.5	0.9	44.2
588		L	2	3	Grain	Canola	0.09	0.87	0.7	40.9	0.09	15.5	3.2	101	43.8	0.7	63.8
588		L	3	3	Grain	Canola	0.07	0.63	0.5	21.4	0.09	15.2	8.1	73.3	27	0.8	47.4
588	PL	L	1	3	Straw	Canola	0.12	0.28	0.6	57	0.1	35.8	2.2	47	8.1	1.3	7
588		L	2	3	Straw	Canola	0.15	0.3	0.2	73.1	0.09	33.7	2.5	73	11.8	1.1	11.9
588		L	3	3	Straw	Canola	0.15	0.3	0.2	65.5	0.1	34	2.6	52	9.3	1.1	12.5
590	PL	U	1	3	Grain	Canola	0.02	1.89	0.2	12.2	0.13	9.5	11.5	61.6	45.6	0.5	35
590		U	2	3	Grain	Canola	0.02	1.14	0.4	13.1	0.14	9.2	6.7	58.3	47.9	0.5	37.3
590		U	3	3	Grain	Canola	0.02	1.33	0.9	15.4	0.13	10.1	2.5	60.9	44.6	0.5	33.7
590	PL	U	1	3	Straw	Canola	0.07	0.77	0.3	70.2	0.73	21	3.5	52.7	19.7	0.5	6
590		U	2	3	Straw	Canola	0.05	0.49	0.2	48.4	0.84	21.8	2	43.5	20.9	0.5	6.8
590		U	3	3	Straw	Canola	0.06	0.65	0.4	49.6	0.89	20.4	2	43.9	17.9	0.5	5.2
590	PL	M	1	3	Grain	Canola	0.02	1.91	0.9	14.2	0.17	9.8	4.3	56.4	45.7	0.5	32.6
590		M	2	3	Grain	Canola	0.02	1.64	1	18.6	0.18	15.1	3.5	57	48.6	0.5	29.2

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
590		M	3	3	Grain	Canola	0.02	1.92	0.7	25.6	0.14	14	4.7	82.2	49.1	0.5	35.9
590	PL	M	1	3	Straw	Canola	0.08	0.96	0.5	58.3	0.93	23.1	2.1	34.5	18.6	0.5	5.4
590		M	2	3	Straw	Canola	0.07	0.82	0.3	47.8	0.66	22.8	3.1	28.3	21.7	0.5	3.4
590		M	3	3	Straw	Canola	0.07	0.88	0.2	66.1	0.72	22.2	1.7	42.1	21.6	0.5	5.7
590	PL	L	1	3	Grain	Canola	0.02	1.54	0.8	12.1	0.13	13.9	2.8	57.6	46.5	0.5	39.9
590		L	2	3	Grain	Canola	0.02	1.22	0.9	10	0.15	11.3	2.5	62.6	44.6	0.5	36.3
590		L	3	3	Grain	Canola	0.02	1.52	1	26.4	0.16	10.9	3.3	70.2	46.8	0.5	34.8
590	PL	L	1	3	Straw	Canola	0.06	0.85	0.2	57.3	0.42	22.2	1.7	43.6	18.2	0.5	9.6
590		L	2	3	Straw	Canola	0.08	0.68	0.5	64.1	0.57	23	1.7	35.9	13.2	0.5	7.7
590		L	3	3	Straw	Canola	0.07	0.79	0.2	70.6	0.5	29	1.6	40.6	18.5	1	9.3
599	PL	U	1	3	Grain	Barley	0.02	0.47	1	216	0.24	1.5	11.3	274	22.1	0.7	48.2
599		U	2	3	Grain	Barley	0.02	0.22	0.7	149	0.25	0.8	10.3	94.1	17.8	0.8	52.6
599		U	3	3	Grain	Barley	0.02	0.2	0.5	159	0.23	1.2	7	75.4	19	0.6	43.7
599	PL	U	1	3	Straw	Barley	0.09	0.38	0.5	707	1.14	9.5	1.5	131	37.7	0.8	21.4
599		U	2	3	Straw	Barley	0.09	0.31	0.4	654	1.1	8.4	1.6	111	33.5	0.5	31
599		U	3	3	Straw	Barley	0.14	0.32	0.7	671	1.08	6.3	1.7	124	40	0.5	21.3
599	PL	M	1	3	Grain	Barley	0.03	0.67	0.6	217	0.23	0.8	9.5	268	21.3	0.5	51.8
599		M	2	3	Grain	Barley	0.02	0.27	0.2	124	0.24	4	12	91.4	19.1	0.5	45.1
599		M	3	3	Grain	Barley	0.03	0.44	0.7	186	0.23	2.1	22.3	184	19	0.5	46.6
599	PL	M	1	3	Straw	Barley	0.11	0.57	0.2	818	1.05	1.9	2.1	362	42.7	0.5	32.6
599		M	2	3	Straw	Barley	0.09	0.26	0.5	626	1.18	6.2	1.6	72.9	36.6	0.5	18.7
599		M	3	3	Straw	Barley	0.09	0.48	0.4	724	1.09	1.4	4.2	345	33.4	0.5	24.2
599	PL	L	1	3	Grain	Barley	0.03	0.33	0.6	153	0.23	1.1	14	126	18.1	1	55.8
599		L	2	3	Grain	Barley	0.03	0.33	0.5	180	0.23	0.8	18.7	128	19.7	0.7	84.1
599		L	3	3	Grain	Barley	0.03	0.25	0.4	140	0.23	0.8	16.9	65.2	17.9	0.6	52.8
599	PL	L	1	3	Straw	Barley	0.09	0.3	0.7	706	1.19	2.2	2.1	167	32.2	0.5	35.8

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
599		L	2	3	Straw	Barley	0.14	0.42	0.8	711	0.95	6.4	1.8	119	37.8	0.5	28.1
599		L	3	3	Straw	Barley	0.08	0.2	0.3	689	1.14	6.4	2.5	65.3	33.5	0.5	36.8
680	BT	U	1	1	Forage	Forage	0.03	1.87	0.3	294	0.47	10.8	3	86.9	47.8	0.8	11.3
680		U	2	1	Forage	Forage	0.05	2.13	0.7	313	0.46	12.3	3.3	89.1	45.2	0.8	15.2
680		U	3	1	Forage	Forage	0.04	1.44	0.2	287	0.51	11.3	3.3	88.7	53.9	0.7	12.8
680	BT	M	1	1	Forage	Forage	0.03	0.46	0.6	262	0.56	6.1	2.4	122	60	1	15
680		M	2	1	Forage	Forage	0.02	0.52	0.4	309	0.52	5.5	2.4	90.7	74	0.6	15
680		M	3	1	Forage	Forage	0.04	0.4	0.2	345	0.47	9.1	2.4	64.5	77.8	0.8	13.4
680	BT	L	1	1	Forage	Forage	0.02	0.71	0.3	218	0.49	18.6	5	71.7	35.7	0.9	16.5
680		L	2	1	Forage	Forage	0.02	0.49	0.4	288	0.42	9.7	3	59.6	41.1	1.1	13.8
680		L	3	1	Forage	Forage	0.02	0.72	0.5	298	0.53	10.8	3.4	140	44.4	1	15.2
680	BT	U	1	2	Forage	Forage	0.07	3.13	0.8	453	0.83	12.8	5.5	177	68.6	1.4	18.7
680		U	2	2	Forage	Forage	0.1	2.88	0.3	446	0.7	23.8	8	218	82.9	1.6	28
680		U	3	2	Forage	Forage	0.08	3.72	0.5	416	0.58	28.9	7.2	185	89.5	1.9	27.2
680	BT	M	1	2	Forage	Forage	0.03	1.06	0.7	503	1	17.8	7.2	153	86.9	1.7	33.2
680		M	2	2	Forage	Forage	0.05	1.98	0.7	507	0.77	19	6.3	220	104	1.6	27.5
680		M	3	2	Forage	Forage	0.06	0.72	0.5	599	0.83	14.3	5.5	166	126	1.4	24.7
680	BT	L	1	2	Forage	Forage	0.03	2.27	0.5	104	0.94	51.2	9.6	120	33.1	2.4	22.2
680		L	2	2	Forage	Forage	0.02	1.75	0.4	106	0.99	45.8	8.9	128	28.9	1.8	18.5
680		L	3	2	Forage	Forage	0.04	2.49	0.7	113	1	45	11	150	42.5	2.2	25.7
688	BT	U	1	3	Grain	Oats	0.02	2.68	0.2	268	0.13	0.9	3.5	60.1	49.8	0.5	27.6
688		U	2	3	Grain	Oats	0.02	2.85	0.4	260	0.13	0.8	2.8	58.7	48.2	0.5	29.2
688		U	3	3	Grain	Oats	0.02	2.4	0.2	212	0.11	3.7	2.9	58.1	48.9	0.7	25.8
688	BT	U	1	3	Straw	Oats	0.05	0.26	0.3	452	1.09	1.5	1.2	47.2	65.8	0.5	10.2
688		U	2	3	Straw	Oats	0.05	0.29	0.2	440	0.92	1.4	1.4	58.1	60.3	0.5	8.5
688		U	3	3	Straw	Oats	0.05	0.29	0.2	516	0.81	0.8	1.2	54	64.2	0.5	6.5

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
688	BT	M	1	3	Grain	Oats	0.02	2.34	0.3	246	0.11	1	2.9	62.2	49.5	0.5	29.5
688		M	2	3	Grain	Oats	0.02	1.95	0.2	230	0.12	0.8	3	65.3	50	0.5	31.8
688		M	3	3	Grain	Oats	0.02	2.53	0.6	226	0.12	0.9	3.3	64.5	49.4	0.5	30.7
688	BT	M	1	3	Straw	Oats	0.02	0.29	0.9	374	0.7	1.7	1.8	56.6	74.2	0.5	12.6
688		M	2	3	Straw	Oats	0.02	0.24	0.3	323	0.62	0.8	1.4	61.5	74.4	0.5	11.2
688		M	3	3	Straw	Oats	0.04	0.27	0.2	344	0.79	0.8	1.3	54.8	72.7	0.5	10.6
688	BT	L	1	3	Grain	Oats	0.03	1.58	0.3	188	0.06	0.8	1.7	214	73.9	0.5	31.4
688		L	2	3	Grain	Oats	0.02	1.1	0.2	182	0.06	0.8	2.1	65.5	49.5	0.5	32.1
688		L	3	3	Grain	Oats	0.02	1.04	0.4	165	0.06	0.8	1.9	56.6	47.6	0.5	30.2
688	BT	L	1	3	Straw	Oats	0.02	0.18	0.4	424	0.34	0.8	1.9	64	61.6	0.5	46.6
688		L	2	3	Straw	Oats	0.02	0.19	0.6	296	0.23	14	2.3	53.1	55.4	1.1	13.5
688		L	3	3	Straw	Oats	0.02	0.18	0.2	358	0.23	11.4	2	52.2	54.8	0.7	10.7
703	BT	U	1	3	Forage	Forage	0.02	1.32	0.2	325	0.52	7.6	2.4	163	79.4	0.8	5.8
703		U	2	3	Forage	Forage	0.03	0.45	0.2	546	0.64	7.5	1.4	234	116	0.7	6.1
703		U	3	3	Forage	Forage	0.07	1.72	0.6	326	0.38	9.1	3	159	73.2	0.9	4.5
703	BT	M	1	3	Forage	Forage	0.05	0.43	0.2	414	0.6	6.8	2.6	179	176	0.6	12.7
703		M	2	3	Forage	Forage	0.05	0.79	0.2	590	0.65	6.2	3.1	1370	135	0.9	10
703		M	3	3	Forage	Forage	0.03	0.32	0.2	281	0.38	3	1.7	151	127	0.5	6.4
703	BT	L	1	3	Forage	Forage	0.03	0.65	0.3	680	0.55	6.2	3.2	256	29.7	1.5	20.4
703		L	2	3	Forage	Forage	0.02	1.03	0.5	607	0.73	4.8	2.4	337	35.4	1.3	17.1
703		L	3	3	Forage	Forage	0.02	0.68	0.5	482	0.68	4.3	2.3	176	26.4	1.4	13.9
727	AP	U	1	3	Grain	Barley	0.02	0.28	0.5	99.8	0.14	0.8	26	75.4	9.5	0.9	50.7
727		U	2	3	Grain	Barley	0.02	0.31	0.4	87	0.15	6.2	25.1	67	9.1	2.3	47.3
727		U	3	3	Grain	Barley	0.02	0.21	0.7	84.3	0.16	3.4	6.6	61.8	9	1.7	42.2
727	AP	U	1	3	Straw	Barley	0.02	0.14	0.3	334	0.35	10.6	2.1	56.6	6.1	0.6	17.2
727		U	2	3	Straw	Barley	0.02	0.15	0.4	408	0.54	7.6	2.2	93.6	6.2	0.5	16.4

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
727		U	3	3	Straw	Barley	0.02	0.16	0.8	353	1.22	6.8	2.3	59.1	5.6	0.5	17.3
727	AP	M	1	3	Grain	Barley	0.02	0.28	0.3	113	0.13	2.2	4.2	60.6	14.6	1.3	37.6
727		M	2	3	Grain	Barley	0.02	0.19	0.6	85.6	0.14	0.9	4.8	64.2	13.6	0.9	37.9
727		M	3	3	Grain	Barley	0.02	0.18	0.6	92	0.15	1	4.4	65.1	15.2	0.8	41.4
727	AP	M	1	3	Straw	Barley	0.02	0.15	0.3	404	0.16	6.1	2.4	67.2	12.8	0.5	11.9
727		M	2	3	Straw	Barley	0.02	0.1	0.6	435	0.22	6.1	2.2	47.7	11.9	0.5	10
727		M	3	3	Straw	Barley	0.02	0.15	0.5	341	0.22	11.6	2.3	51.4	16.5	0.8	10.8
727	AP	L	1	3	Grain	Barley	0.02	0.15	0.3	90.4	0.18	1	13.9	57.8	16.3	0.7	40.9
727		L	2	3	Grain	Barley	0.02	0.26	0.4	76.2	0.18	0.8	28.7	58.7	16.4	0.5	48.8
727		L	3	3	Grain	Barley	0.02	0.23	0.4	89.4	0.19	0.8	13.3	84.5	18	0.7	42.6
727	AP	L	1	3	Straw	Barley	0.03	0.16	0.2	380	0.39	8.9	3	65.8	19.2	0.5	16.7
727		L	2	3	Straw	Barley	0.02	0.16	0.2	367	0.41	6.8	3	71.4	20.7	0.5	18.4
727		L	3	3	Straw	Barley	0.02	0.18	0.2	327	0.58	6.4	2.8	74	22.6	0.5	19.2
728	AP	U	1	3	Grain	Canola	0.02	1.3	0.2	10	0.08	20.9	1.7	88.1	42.9	1.4	41.3
728		U	2	3	Grain	Canola	0.04	1.04	0.2	11.3	0.09	19.1	4.9	111	42.2	1.3	38.7
728		U	3	3	Grain	Canola	0.03	0.32	0.2	10.2	0.09	19.6	10.4	63.2	44.6	1	38.3
728	AP	U	1	3	Straw	Canola	0.1	0.16	1	53.3	0.48	26.8	2.5	34.9	19.1	0.5	6.9
728		U	2	3	Straw	Canola	0.11	0.13	0.4	66.1	0.44	34.9	2.3	45.8	19.6	1	9
728		U	3	3	Straw	Canola	0.11	0.16	1	50.9	0.41	29.6	2.5	42.4	18.7	0.6	7.5
728	AP	M	1	3	Grain	Canola	0.02	0.37	0.2	10.3	0.08	16.1	4.3	73.7	42.4	30.2	40
728		M	2	3	Grain	Canola	0.03	0.3	1	6	0.08	15.4	3	72.3	42.9	1	40.8
728		M	3	3	Grain	Canola	0.02	0.35	0.9	5	0.08	15.2	5.5	73.5	41.1	0.9	41.9
728	AP	M	1	3	Straw	Canola	0.09	0.11	0.7	60	0.64	29	2	44.7	21.4	0.5	7.3
728		M	2	3	Straw	Canola	0.11	0.13	1	54.2	0.48	29.2	14.4	37.1	20.9	0.5	7.2
728		M	3	3	Straw	Canola	0.1	0.17	0.6	53.7	0.64	39.4	2.5	40.8	19	1	9
728	AP	L	1	3	Grain	Canola	0.02	0.25	1	7.6	0.1	14.3	1.9	77.6	36.3	1.4	53.3

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
728		L	2	3	Grain	Canola	0.02	0.24	0.2	26.9	0.09	14.8	8	103	40	0.8	61.2
728		L	3	3	Grain	Canola	0.02	0.22	0.9	9.4	0.09	13.2	2.5	80.1	36	1.2	58.1
728	AP	L	1	3	Straw	Canola	0.03	0.11	0.2	32.3	0.43	27.7	2.4	37.1	13.7	0.6	18
728		L	2	3	Straw	Canola	0.05	0.16	0.2	43.7	0.46	26.2	2.4	45	16.7	1	18
728		L	3	3	Straw	Canola	0.06	0.15	0.2	55.5	0.47	28.1	2.3	58.1	17.8	0.9	18.9
739	AP	U	1	3	Grain	Wheat	0.02	0.51	0.3	19.9	0.06	2	41.6	45.4	54.8	0.5	52.5
739		U	2	3	Grain	Wheat	0.05	0.42	0.5	11.9	0.07	1.6	4.4	42.2	55.2	0.5	47.4
739		U	3	3	Grain	Wheat	0.04	0.49	0.6	17.7	0.07	1.7	29.9	44.7	52	0.5	52.2
739	AP	U	1	3	Straw	Wheat	0.11	0.46	0.6	421	0.08	6.1	2.8	121	47.2	0.5	19.3
739		U	2	3	Straw	Wheat	0.13	0.49	0.2	477	0.1	5.8	2.7	90.8	48.1	0.5	13.8
739		U	3	3	Straw	Wheat	0.1	0.27	0.3	434	0.1	5	2.4	100	42.1	0.5	14.9
739	AP	M	1	3	Grain	Wheat	0.04	0.51	0.2	15.1	0.06	1	32.8	55.9	51.2	0.5	51
739		M	2	3	Grain	Wheat	0.04	0.39	0.7	13.4	0.06	0.8	21	42.9	49.1	0.5	45.6
739		M	3	3	Grain	Wheat	0.03	0.51	0.3	18.6	0.07	0.8	33.3	47.8	49.3	0.5	45.5
739	AP	M	1	3	Straw	Wheat	0.08	0.26	0.2	438	0.09	10.3	2.8	120	38.3	0.9	15
739		M	2	3	Straw	Wheat	0.08	0.31	0.2	411	0.11	7.6	4.9	139	40.8	0.5	12.9
739		M	3	3	Straw	Wheat	0.1	0.29	0.2	417	0.12	7.3	2.2	108	38.7	0.5	11.3
739	AP	L	1	3	Grain	Wheat	0.02	0.35	0.6	19.6	0.06	14.8	17	49.3	42.2	2	38.5
739		L	2	3	Grain	Wheat	0.03	0.32	0.2	19.1	0.07	10	5.6	56.1	49.1	1	38.6
739		L	3	3	Grain	Wheat	0.03	0.31	0.5	11.8	0.07	8.7	5.2	45.4	50.8	0.7	37
739	AP	L	1	3	Straw	Wheat	0.07	0.3	0.2	612	0.24	5.6	2	81.3	28.7	0.5	8.3
739		L	2	3	Straw	Wheat	0.08	0.2	0.3	482	0.2	4.9	2.6	89.6	32.3	0.5	8.5
739		L	3	3	Straw	Wheat	0.07	0.27	0.2	456	0.21	5.7	4.1	84.3	37	0.5	8.1
743	AP	U	1	3	Grain	Wheat	0.04	0.59	0.2	13.4	0.08	6.8	5.8	52.5	49.6	1.2	22.3
743		U	2	3	Grain	Wheat	0.03	0.55	0.2	16.3	0.07	6.1	5.8	77	50.7	1.2	25.6
743		U	3	3	Grain	Wheat	0.03	0.49	0.2	17.8	0.07	5.7	6.3	61.6	53	1.1	21.6

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
743	AP	U	1	3	Straw	Wheat	0.08	0.14	0.7	403	0.65	6.9	2.2	56.7	31.5	0.8	5.7
743		U	2	3	Straw	Wheat	0.06	0.17	0.5	336	0.64	7.7	1.7	82.3	31	0.6	5
743		U	3	3	Straw	Wheat	0.05	0.28	0.6	378	0.54	6.5	2.2	113	32.4	0.8	6.3
743	AP	M	1	3	Grain	Wheat	0.04	0.59	0.2	12.4	0.1	9.3	5	60.6	49.6	0.6	42.2
743		M	2	3	Grain	Wheat	0.04	0.67	0.2	13.7	0.09	3.7	40.3	60.3	50.1	0.5	41.5
743		M	3	3	Grain	Wheat	0.04	0.48	0.2	12.7	0.09	3.1	25.2	59	52.3	0.5	36.2
743	AP	M	1	3	Straw	Wheat	0.11	0.23	1.1	391	0.4	8.9	2.4	81.5	37.8	0.7	7.8
743		M	2	3	Straw	Wheat	0.13	0.26	1.5	419	0.41	5.8	2.7	65.8	36	0.5	6.5
743		M	3	3	Straw	Wheat	0.12	0.27	1.8	408	0.38	4.9	2.6	57.5	44	0.5	7
743	AP	L	1	3	Grain	Wheat	0.08	0.96	0.5	10	0.11	3.3	21.8	82.5	83.5	0.5	63
743		L	2	3	Grain	Wheat	0.06	0.83	0.4	14.2	0.11	6.2	3.2	99.3	90.2	0.5	65.9
743		L	3	3	Grain	Wheat	0.08	1	0.9	16.1	0.1	5.1	3.1	71.8	85.7	0.6	60.7
743	AP	L	1	3	Straw	Wheat	0.21	0.35	0.3	276	0.51	3	1.7	66.2	108	5.2	16.7
743		L	2	3	Straw	Wheat	0.19	0.38	0.2	370	0.56	2.4	1.6	118	114	0.5	20.3
743		L	3	3	Straw	Wheat	0.17	0.34	0.2	302	0.49	0.8	1.5	79.4	97.2	0.5	31.5
769	MM	U	1	3	Grain	Wheat	0.03	0.64	0.6	32.8	0.06	3.5	4	438	65.5	0.8	21.2
769		U	2	3	Grain	Wheat	0.04	0.44	0.6	33.6	0.06	2.7	4	67	53.4	0.5	25.8
769		U	3	3	Grain	Wheat	0.04	0.51	0.6	18.3	0.07	2.2	20.7	63.3	57.5	0.5	30.8
769	MM	U	1	3	Straw	Wheat	0.17	0.51	0.3	695	0.1	0.8	2.9	341	66.9	0.5	10.2
769		U	2	3	Straw	Wheat	0.16	0.38	0.6	522	0.08	0.8	2.6	210	64.5	0.5	7.3
769		U	3	3	Straw	Wheat	0.18	0.29	0.3	472	0.11	0.8	1.8	123	76.4	0.5	8.9
769	MM	M	1	3	Grain	Wheat	0.04	0.47	0.6	16.1	0.07	2.4	2.8	94.4	54.1	0.5	40.3
769		M	2	3	Grain	Wheat	0.04	0.66	0.5	13.7	0.07	2.4	37.6	75.6	65.2	0.5	56
769		M	3	3	Grain	Wheat	0.02	0.5	0.4	14.1	0.07	3.1	3.6	74.7	70	0.5	54.9
769	MM	M	1	3	Straw	Wheat	0.21	0.41	0.5	519	0.22	0.8	1.4	143	68.4	0.5	10.4
769		M	2	3	Straw	Wheat	0.21	0.43	0.2	521	0.19	0.8	3.6	173	91.6	0.5	23.3

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
769		M	3	3	Straw	Wheat	0.21	0.47	0.4	487	0.38	0.8	4.2	148	97.7	0.5	25.4
769	MM	L	1	3	Grain	Wheat	0.03	0.59	0.6	13.3	0.08	2.3	20.3	63.9	67.4	0.5	51.2
769		L	2	3	Grain	Wheat	0.04	0.46	0.5	9.3	0.08	6.8	2.7	64.2	71	0.8	49
769		L	3	3	Grain	Wheat	0.04	0.45	0.3	16.9	0.08	5.5	2.1	64.9	61.3	0.5	40.8
769	MM	L	1	3	Straw	Wheat	0.19	0.35	0.2	407	0.55	0.8	1.6	132	97.1	0.5	15
769		L	2	3	Straw	Wheat	0.23	0.48	0.4	549	0.52	1.8	2	155	108	0.5	16.8
769		L	3	3	Straw	Wheat	0.19	0.31	0.2	469	0.31	0.8	3.7	128	78.6	0.5	10.6
786	MM	U	1	3	Forage	Forage	0.07	0.67	0.7	260	0.32	12.1	3.5	105	31.1	0.8	15.2
786		U	2	3	Forage	Forage	0.03	0.23	0.6	334	0.4	6.8	2.2	83.4	29	0.9	5.6
786		U	3	3	Forage	Forage	0.05	0.49	0.5	365	0.22	10.7	3.8	134	30.9	1	33.8
786	MM	M	1	3	Forage	Forage	0.1	0.98	0.6	251	0.22	12.1	3.6	140	26.1	0.9	11.6
786		M	2	3	Forage	Forage	0.18	1.71	0.6	223	0.21	20.1	4.8	129	24	0.6	18.1
786		M	3	3	Forage	Forage	0.1	0.53	0.2	429	0.23	7.1	5.6	239	42.2	0.6	13.9
786	MM	L	1	3	Forage	Forage	0.2	1.27	0.2	224	0.28	8.1	2.2	88.4	55.9	0.5	14.3
786		L	2	3	Forage	Forage	0.16	3.18	0.2	203	0.35	16.6	3	113	37	1.6	57.2
786		L	3	3	Forage	Forage	0.14	0.76	0.3	259	0.26	13	2.5	96.1	42.4	0.9	28.8
791	MM	U	1	3	Grain	Canola	0.07	1.62	0.7	166	0.07	14	2.7	317	43.9	0.8	47.1
791		U	2	3	Grain	Canola	0.09	1.62	0.5	48.4	0.07	14.1	3.1	81.5	36.2	0.7	40.9
791		U	3	3	Grain	Canola	0.1	1.72	0.9	44.1	0.07	13.8	3.2	89.3	39.5	0.9	44.8
791	MM	U	1	3	Straw	Canola	0.24	0.62	0.8	108	0.12	15.1	2.5	51.6	21.5	0.5	10.4
791		U	2	3	Straw	Canola	0.22	0.62	0.3	96.3	0.16	13.6	2.3	51	16.6	0.5	10.8
791		U	3	3	Straw	Canola	0.24	0.58	1	84.7	0.11	14.7	2.4	44.2	18.3	0.6	11.3
791	MM	M	1	3	Grain	Canola	0.04	0.87	0.8	41.4	0.06	12.6	2.9	83.3	39.7	0.8	38.6
791		M	2	3	Grain	Canola	0.06	0.83	0.5	39.5	0.06	11.6	3.4	75.5	38.2	0.9	35.8
791		M	3	3	Grain	Canola	0.05	0.98	0.2	20.2	0.05	10.9	2.3	75.9	34.3	0.6	43.2
791	MM	M	1	3	Straw	Canola	0.09	0.29	0.7	78.3	0.12	14.9	2.2	46.2	21.6	0.5	8.9

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
791		M	2	3	Straw	Canola	0.13	0.41	0.9	83.8	0.1	11.9	1.8	44.3	18.4	0.5	7.3
791		M	3	3	Straw	Canola	0.14	0.42	0.2	100	0.09	18.1	2.6	65.3	15.5	0.5	12.9
800	FG	U	1	3	Grain	Barley	0.05	0.34	0.5	116	0.04	1.9	21.7	66.7	14.9	1.1	52
800		U	2	3	Grain	Barley	0.04	0.29	1	114	0.04	0.8	19.4	61.4	13	0.5	39.5
800		U	3	3	Grain	Barley	0.03	0.21	0.9	98	0.04	0.8	28.1	55.6	15.3	0.6	53
800	FG	U	1	3	Straw	Barley	0.11	0.17	0.2	560	0.05	1.1	3.1	61	18	0.5	11
800		U	2	3	Straw	Barley	0.08	0.22	0.2	562	0.05	4.5	2.7	80.8	17	0.5	22.1
800		U	3	3	Straw	Barley	0.12	0.21	0.6	591	0.04	0.8	3.2	71.1	20.5	0.5	12.4
800	FG	M	1	3	Grain	Barley	0.05	0.22	1	111	0.08	0.8	5	49.7	14	0.5	48
800		M	2	3	Grain	Barley	0.04	0.25	1	101	0.08	0.8	8.7	58.2	14.8	0.5	37.9
800		M	3	3	Grain	Barley	0.05	0.32	1	125	0.09	0.8	11.2	60.8	15.1	0.5	38.8
800	FG	M	1	3	Straw	Barley	0.13	0.22	0.7	618	0.07	3.1	4.1	74	20.1	0.5	9.3
800		M	2	3	Straw	Barley	0.11	0.23	0.5	353	0.07	5.2	3.8	53.9	20	0.5	15.2
800		M	3	3	Straw	Barley	0.13	0.26	0.6	627	0.08	6.1	3.5	81.6	21.5	0.5	13.5
800	FG	L	1	3	Grain	Barley	0.04	0.27	0.5	128	0.06	0.8	10.5	64.2	14.6	0.5	43
800		L	2	3	Grain	Barley	0.02	0.29	0.8	124	0.05	17	18.1	60.6	15.6	1	46.7
800		L	3	3	Grain	Barley	0.04	0.31	0.6	150	0.05	5.5	12.8	66.2	15	0.5	45.6
800	FG	L	1	3	Straw	Barley	0.13	0.22	0.5	649	0.06	2.8	3.3	66	21.2	0.5	15.2
800		L	2	3	Straw	Barley	0.13	0.21	0.6	445	0.05	0.8	3.5	43.6	20.5	0.5	17.2
800		L	3	3	Straw	Barley	0.12	0.47	0.4	659	0.06	1.5	3.3	74.5	21.7	0.5	15
806	MG	U	1	3	Grain	Wheat	0.17	0.38	1.4	26.7	0.07	6.3	5.2	40.2	24.2	0.8	45
806		U	2	3	Grain	Wheat	0.24	0.53	0.6	34.1	0.07	5.3	37.7	47.1	21.4	0.6	44.2
806		U	3	3	Grain	Wheat	0.18	0.4	1.1	34.5	0.06	4.3	12.6	52.7	19.4	0.9	45.1
806	MG	U	1	3	Straw	Wheat	0.16	0.3	0.8	755	0.78	5.1	3.2	96.8	12.8	0.5	10.8
806		U	2	3	Straw	Wheat	0.26	0.44	0.3	581	0.67	1.6	2.1	156	13.3	0.5	13.1
806		U	3	3	Straw	Wheat	0.16	0.32	0.7	689	0.46	3.2	3.7	138	12.8	0.5	8.4

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
806	MG	M	1	3	Grain	Wheat	0.23	0.51	0.6	32.7	0.06	4.4	4.8	69.7	29.3	0.5	49
806		M	2	3	Grain	Wheat	0.2	0.42	3.4	29	0.07	3.8	5.6	72.9	25	1	45.2
806		M	3	3	Grain	Wheat	0.23	0.49	1.4	28.6	0.07	3.8	17.9	44.4	29.4	0.5	44.2
806	MG	M	1	3	Straw	Wheat	0.29	0.36	0.4	619	0.7	0.8	1.4	112	18	0.5	8.4
806		M	2	3	Straw	Wheat	0.28	0.68	2.3	654	1.11	5.8	1.7	150	12.9	0.5	6.2
806		M	3	3	Straw	Wheat	0.28	0.35	1	721	0.81	4.5	1.2	114	16.6	0.5	11.4
806	MG	L	1	3	Grain	Wheat	0.27	0.22	0.3	29	0.08	8.3	7.3	42	33.3	1.5	47.2
806		L	2	3	Grain	Wheat	0.34	0.47	0.6	43.1	0.09	6.9	5.9	80.1	38.1	0.8	51.6
806		L	3	3	Grain	Wheat	0.29	0.36	0.3	38	0.08	4.5	6.2	44.3	32.6	0.7	47.3
806	MG	L	1	3	Straw	Wheat	0.36	0.25	0.7	493	0.55	1.1	2.9	133	28.2	0.5	15.2
806		L	2	3	Straw	Wheat	0.42	0.33	0.5	662	0.62	0.8	1.6	178	32.9	0.5	17.6
806		L	3	3	Straw	Wheat	0.35	0.17	0.2	660	0.48	0.8	2.8	108	26	0.5	13.4
812	MG	U	1	1	Forage	Forage	0.03	2.32	0.6	81	0.51	57.8	9.4	86.1	20.1	2.4	25.8
812		U	2	1	Forage	Forage	0.04	1.99	0.2	75.4	0.51	56.3	9.1	76.6	17.1	2.1	25.9
812		U	3	1	Forage	Forage	0.05	1.82	0.8	91	0.48	51.3	9.9	96.4	18.7	1.9	25.6
812	MG	M	1	1	Forage	Forage	0.04	1.92	0.2	82.7	0.57	47.1	9.1	76.1	16	2.3	21.3
812		M	2	1	Forage	Forage	0.03	1.86	0.6	82.1	0.53	48.4	9.3	86.5	14.9	2.2	23.9
812		M	3	1	Forage	Forage	0.04	2	0.5	73.3	0.55	48.8	9.7	82.7	13.8	2.3	23.9
812	MG	L	1	1	Forage	Forage	0.02	1.38	0.2	83.6	0.48	51.3	10.1	92.1	16	3.5	26
812		L	2	1	Forage	Forage	0.04	1.6	0.5	56.8	0.51	42.3	7.5	72.6	15.1	2	13
812		L	3	1	Forage	Forage	0.02	1.48	0.2	26.1	0.56	42.3	9.2	81	16	1.9	20.4
812	MG	U	1	2	Forage	Forage	0.02	2.08	0.3	59.8	0.5	47.5	8.8	127	21.8	2.2	24.9
812		U	2	2	Forage	Forage	0.02	1.81	0.3	52.2	0.6	46.3	9	118	21.7	2	29.6
812		U	3	2	Forage	Forage	0.02	1.82	0.5	88.3	0.59	46.1	9.3	133	21.1	2.3	24.3
812	MG	M	1	2	Forage	Forage	0.02	1.82	0.6	41	0.72	41.2	9.3	97.1	22.6	1.7	19.4
812		M	2	2	Forage	Forage	0.02	2.1	0.3	59.2	0.67	43.9	9.8	100	20.7	2.2	23

Appendix 1. Micronutrient values for 17 Benchmark Sites

Site #	Eco-Region[1]	Slope Pos	Rep	Cut	Grain/ Straw	Crop	Cd (mg/kg)	Ni (mg/kg)	Se (mg/kg)	Si (mg/kg)	Cl (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
812		M	3	2	Forage	Forage	0.02	2.11	0.2	61.2	0.73	41.7	9.6	117	22.1	1.9	25.2
812	MG	L	1	2	Forage	Forage	0.02	1.5	0.3	61.6	0.7	37.3	9.5	99.6	24.5	1.6	20.3
812		L	2	2	Forage	Forage	0.02	1.92	0.4	70.4	0.7	32	8.2	108	24.1	1.6	17.7
812		L	3	2	Forage	Forage	0.02	1.96	0.2	64.3	0.72	35.8	10	104	23	1.3	22.8
815	MG	U	1	3	Forage	Forage	0.05	0.71	1.2	65.1	0.15	42.6	5.9	108	26.7	1.7	11.4
815		U	2	3	Forage	Forage	0.06	0.88	1	67.2	0.17	40.4	7.4	141	26.3	3.2	15.4
815		U	3	3	Forage	Forage	0.04	0.67	1.4	82.2	0.17	43.9	6.4	132	26.7	1.9	11.8
815	MG	M	1	3	Forage	Forage	0.05	1.06	1.5	58.5	0.21	40.2	6.9	85.8	31.6	2.5	12.2
815		M	2	3	Forage	Forage	0.02	0.91	1.3	66.4	0.21	53	8	99.3	24.6	3.7	11.8
815		M	3	3	Forage	Forage	0.05	0.77	1.6	62.8	0.15	48.5	6.8	97	26.7	2.3	12.8
815	MG	L	1	3	Forage	Forage	0.21	1.64	0.5	67.9	0.19	45.6	6.9	88.8	28.9	1.8	22.4
815		L	2	3	Forage	Forage	0.22	1.66	0.6	52.2	0.21	43.4	8	98.4	30.5	1.3	25.9
815		L	3	3	Forage	Forage	0.29	1.82	0.4	36.6	0.24	46.7	7.5	79.6	28.2	0.7	26

Appendix 2. Calculated mean, max, min and standard deviation of pH_w and pH_c for all Sites

	pH_w				pH_c			
Site	**Mean**	**Max**	**Min**	**Stdev**	**Mean**	**Max**	**Min**	**Stdev**
588	7.67	8.20	6.51	0.66	7.25	7.76	5.97	0.74
590	6.60	7.20	6.00	0.52	5.80	6.30	5.40	0.38
599	6.66	7.68	5.94	0.62	5.80	7.14	5.00	0.81
680	6.57	6.80	6.40	0.20	5.80	6.10	5.50	0.20
688	6.57	6.84	6.33	0.22	5.47	5.73	5.23	0.22
703	7.15	7.75	6.66	0.48	6.18	7.01	5.63	0.62
727	6.23	6.70	5.80	0.39	5.62	6.20	5.10	0.44
728	6.68	7.27	6.24	0.38	5.77	6.52	5.26	0.45
739	6.30	6.95	5.89	0.38	5.44	6.27	5.03	0.47
743	6.56	7.72	5.50	0.92	5.78	7.22	4.71	1.08
769	5.54	6.38	5.00	0.48	4.84	5.77	4.42	0.49
786	6.94	7.83	6.28	0.62	6.23	7.28	5.32	0.79
791	5.80	8.01	0.62	3.01	5.28	7.44	0.79	2.68
800	6.14	6.26	6.06	0.08	5.31	5.49	5.13	0.13
806	7.48	8.06	5.97	0.79	6.81	7.37	5.03	0.90
812	8.18	8.27	8.09	0.07	7.61	7.70	7.46	0.10
815	7.58	8.42	6.04	1.09	6.60	7.46	5.12	1.06

Appendix 2.1. Calculated mean, max, min and standard deviation of pH_w and pH_c for all ecoregions

	pH_w				pH_c			
Ecoregion	**Mean**	**Max**	**Min**	**Stdev**	**Mean**	**Max**	**Min**	**Stdev**
PL	6.98	8.20	5.94	0.76	6.28	7.76	5.00	0.94
BT	6.76	7.75	6.33	0.42	5.82	7.01	5.23	0.48
AP	6.44	7.72	5.50	0.56	5.65	7.22	4.71	0.64
MM	6.45	8.01	5.00	0.96	5.75	7.44	4.42	1.03
FG	6.14	6.26	6.06	0.08	5.31	5.49	5.13	0.13
MG	7.75	8.42	5.97	0.80	7.01	7.70	5.03	0.88