AESA

Soil Quality Benchmark Sites

Micronutrients

Copper, Iron, Manganese and Zinc

Four essential micronutrients, copper, iron, manganese and zinc, were measured at the Alberta Environmentally Sustainable Agriculture (AESA) Soil Quality Benchmark Sites. Copper is very important for a plant's reproductive growth stage and affects chlorophyll production. Iron is critical for chlorophyll formation and photosynthesis, and important in plant enzyme systems and respiration. Manganese is important in carbohydrate and nitrogen metabolism. Zinc is essential for sugar regulation and enzymes that control plant growth, especially root growth.

Summary

Results from 43 sites across Alberta show some important differences in levels of the micronutrients copper, iron, manganese and zinc based on soil properties, slope position and agricultural ecoregion. Although micronutrient deficiencies were not widespread, 19 per cent of the topsoil samples were deficient in copper, and 11 per cent were deficient in zinc.

At some sites, micronutrient levels ranged from deficient on the upper slope to more than adequate at the lower slope. None of the samples had potentially toxic levels of copper, iron or zinc. The few samples with potentially toxic manganese levels were associated with low pH (acidic) soils.

Soil organic matter, pH and clay content had the greatest influence on micronutrient levels. The strong influence of soil organic matter was evident as both organic matter and micronutrient levels increased from the upper to lower slopes of many sites. This finding highlights the importance of agricultural practices that minimize soil erosion and conserve soil organic matter. It also indicates that micronutrient deficiencies tend to occur in patches rather than throughout a field.

Soil organic matter, pH and clay content also influenced the relationship between micronutrient levels and ecoregions (areas of similar soils, landforms, climate and vegetation). For example, low zinc values occurred most frequently in the Mixed Grasslands Ecoregion in Southern Alberta where the soils generally have low soil organic matter and high pH.

What are Micronutrients?

Nutrients essential for plant growth are categorized as ***macronutrients*** (such as nitrogen, phosphorus and potassium) and ***micronutrients***. Micronutrients are just as essential as macronutrients but are required in smaller amounts by plants. There are eight essential micronutrients: copper, zinc, iron, manganese, boron, chloride, molybdenum and nickel.

Why are Micronutrients Important?

Crop growth, quality and/or yield may be affected if any one of the eight essential micronutrients is lacking in the soil or is not adequately balanced with other nutrients.

Micronutrient Availability to Plants

The availability of a micronutrient to plants is determined by both the total amount of the nutrient in the soil and the soil's properties. Other factors, such as crop species and variety, can also influence the degree to which micronutrient levels affect crop production.

The main soil properties affecting the availability of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn):

- **pH** – these micronutrients become less available as the soil becomes more alkaline, that is, as soil pH increases.
- **soil organic matter content** – soil organic matter holds micronutrients in both plant-available and unavailable forms. Low organic matter soils usually have less available copper, iron, manganese and zinc than soils with moderate amounts of organic matter. However high organic matter soils can also have low plant-available micronutrient levels because organic matter can tie up the micronutrients in unavailable forms. In particular, Cu becomes less available as soil organic matter content increases.
- **clay content** – clay soils are likely to have higher levels of micronutrients, and sandy soils are likely to have lower levels.

Free lime ($CaCO_3$), soil temperature and soil moisture also influence micronutrient availability. Free lime precipitates and adsorbs the micronutrients, making them less available to plants. Cool, wet soils can reduce the rate and amount of micronutrients taken up by crops.

Crop type, variety and growing conditions can affect whether or not a micronutrient deficiency will occur. For example, wheat, barley and oat are prone to copper deficiency, and beans and corn are prone to zinc deficiency. As well, some oat varieties are much more prone to manganese deficiency than others. Good growing conditions for crops generally favor nutrient uptake, but high yields also increase the nutrient requirements of crops.

Past research and observations have shown that micronutrient deficiencies are less common in Alberta than in many other parts of the world. Toxic levels are also uncommon in Alberta soils.

AESA Soil Quality Benchmark Sites

The AESA Program, in conjunction with the province's agri-food industry, initiated the Soil Quality Benchmark Sites in 1998. The benchmarks' objectives are to identify and monitor agricultural impacts on soil resources and to collect soil information to help develop environmentally sustainable agricultural practices.

Forty-three benchmark sites were established and located on typical farm fields throughout the province's agricultural areas, in seven agricultural ecoregions (Figure 1). (The Mixed Boreal Uplands Ecoregion had only one monitoring site, so its results are not included in this summary.)

Ecoregion Approach

The AESA Soil Quality Benchmark Sites are located to be representative of different ecoregions and ecodistricts. An ecoregion is an area of similar soils, landforms, climate and vegetation; an ecodistrict is a subdivision of an ecoregion. Using this ecoregion approach, researchers are better able to compare data and evaluate broad trends.

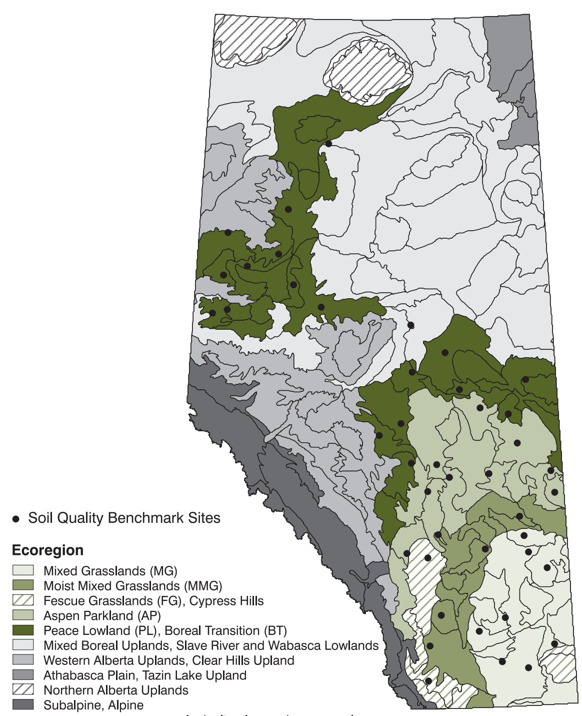

Figure 1.

Locations of AESA Soil Quality benchmark sites, ecoregions and ecodistricts

Information is collected for each benchmark site concerning landforms, soil profile, soil and crop management practices as well as soil properties. Soil properties are measured at three sampling locations – upper slope, mid slope and lower slope – for each of the 43 sites. This detailed sampling approach allows variations within a field to be assessed along with broad regional trends.

Micronutrient Project

The micronutrient status of the benchmark sites was assessed in 2001. Researchers conducted a one-year project to measure levels of copper, iron, manganese and zinc and to assess the influence of ecoregion, slope position and soil characteristics on the levels of these four micronutrients in the topsoils and subsoils at the 43 sites.

Copper and zinc were selected for analysis because previous research and observations showed that they are the micronutrients most likely to be deficient in Alberta soils. Iron and manganese were included because they can be extracted using the same laboratory procedure as copper and zinc.

Soil Sampling and Analysis

Samples of the topsoil (A horizon) and subsoil (B horizon) were taken at the upper, mid and lower slope positions at each site. The samples were analyzed for copper, iron, manganese, and zinc along with a wide range of other chemical and physical characteristics, including soil organic matter content, soil texture and pH.

A commonly used procedure (called diethylenetriaminepentaacetic acid or DTPA extraction) was used to extract Cu, Fe, Mn and Zn from the samples. The extractable amounts of the micronutrients are an estimate of the plant-available levels. However, they are not identical to plant-available levels because soil properties and other factors affect availability, as noted earlier.

The micronutrient status of each benchmark site and slope position was categorized as deficient, marginal or adequate, based on the extractable concentrations (Table 1). Micronutrient levels are represented in milligrams per kilogram (mg/kg) which is the same as parts per million (ppm).

Table 1.
Ranges for extractable micronutrient levels in soils

Micronutrient	Concentration (mg/kg)		
	Deficient	Marginal	Adequate
Copper			
• soil with less than 7% organic matter	0.0 - 0.4	0.5 - 0.6	> 0.6
• soil with more than 7% organic matter	0.0 - 0.6	0.7 - 1.0	> 1.0
Iron	0.0 - 2.0	2.0 - 4.5	> 4.5
Manganese	0.0 - 1.0	–	> 1.0
Zinc	0.0 - 0.5	0.6 - 1.0	> 1.0

Sources: McKenzie, Ross. 1992. *Micronutrient Requirements of Crops*. Agdex 531-1. Alberta Agriculture, Food and Rural Development; and Solberg, Elston et al. 1999. *Copper Deficiency: Diagnosis and Correction*. Agdex 532-3. Alberta Agriculture, Food and Rural Development.

Results

As expected from previous research, extractable levels of the four micronutrients were most strongly affected by soil organic matter content, pH and clay content (Table 2). The effects of these soil properties can also been seen when the results are considered by ecoregion and slope position.

Table 2.
Summary of strong relationships between extractable micronutrient levels and soil properties

Micronutrient	Clay	Organic Matter (OM)	pH
Copper (Cu)	more clay, more Cu	more OM, more Cu	
Iron (Fe)		more OM, more Fe	higher pH, less Fe
Manganese (Mn)			higher pH, less Mn
Zinc (ZN)		more OM, more Zn	

A. Soil-related trends

Copper

- 19 per cent of the topsoil samples and 17 per cent of the subsoil samples were deficient in copper.
- Clay and organic matter content had the greatest influence on extractable copper.
- Extractable copper generally decreased as the clay content decreased. Thus, as expected, sandy soils were much more likely to be copper-deficient than clay soils.
- Extractable copper generally increased as the organic matter content increased. However, for soils with high organic matter levels, some of this extractable copper may be held in forms not available to plants. Thus, both low and high levels of soil organic matter can result in low plant-available copper.
- None of the samples had extractable copper values in the toxic range.

Iron

- None of samples had extractable iron in the deficient or marginal ranges.
- Soil organic matter and pH had the strongest influence on iron levels. Iron levels decreased as pH increased and as organic matter decreased.
- None of the samples had extractable iron values in the toxic range.

Manganese

- None of the topsoil samples and only one subsoil sample was in the deficient range.
- Soil pH had the strongest influence on extractable manganese levels, with manganese decreasing as pH increased.
- Relatively high extractable manganese (>35 mg/kg) occurred at five sites with low pH soils.

Zinc

- 11 per cent of the topsoil samples and 28 per cent of the subsoil samples were deficient in zinc.
- Soil organic matter had the strongest influence on extractable zinc, with zinc decreasing as organic matter decreased.
- None of the samples had extractable zinc values in the toxic range.

B. Ecoregion trends

Micronutrient levels and soil properties are summarized for each ecoregion in Table 3. The relationships of micronutrient levels to the ecoregions were not as strong as the relationships of micronutrient levels to soil properties. This difference is because of the relatively large variation in soil properties within each ecoregion.

Table 3.
Extractable micronutrient levels and soil properties for each ecoregion

Ecoregion	Number of Sites	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)	Clay (%)	Organic Matter (%)	pH
Peace Lowland	10	1.1	160	12.9	7.8	36	6.2	6.5
Boreal Transition	8	0.8	123	16.1	3.5	26	5.5	6.3
Aspen Parkland	9	0.7	106	20.1	4.7	21	6.2	6.3
Moist Mixed Grasslands	5	0.8	98	24.7	2.0	18	5.0	6.2
Fescue Grasslands	2	1.3	92	28.9	2.3	29	5.7	6.3
Mixed Grasslands	8	0.9	39	11.8	0.8	24	1.8	7.2

Copper

The highest frequency of deficient and marginal copper values occurred in the ecoregions in Central Alberta (Boreal Transition, Aspen Parkland and Moist Mixed Grasslands). These results are consistent with research and observation of a relatively high frequency of copper deficiency on sandy loam and light loam soils in Central Alberta. A common characteristic of copper-deficient soils in the Aspen Parkland and Boreal Transition ecoregions is low clay and/or high organic matter content.

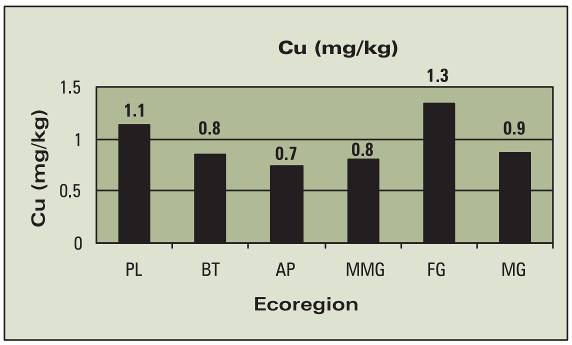

Figure 2.

Copper level by ecoregion

Iron

The lowest extractable iron values occurred in the Mixed Grasslands Ecoregion on soils with low organic matter (<2 per cent), high pH ($\geq$8.0) and high free lime. In this ecoregion, iron deficiency symptoms are common on some species of trees, shrubs and ornamentals (but iron deficiencies have not been found in field crops in this or any other ecoregion in Alberta).

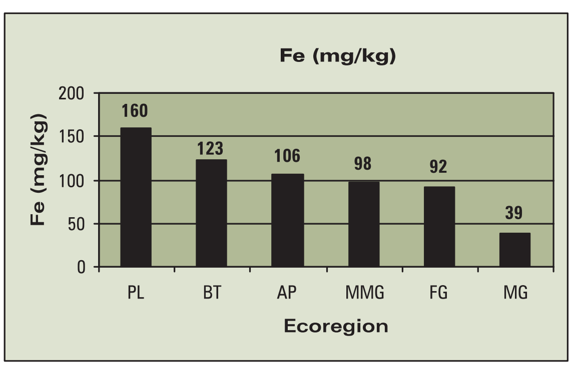

Figure 3.

Iron level by ecoregion

Manganese

The highest manganese values occurred in the four ecoregions with the lowest pH (Boreal Transition, Aspen Parkland, Moist Mixed Grasslands and Fescue Grasslands).

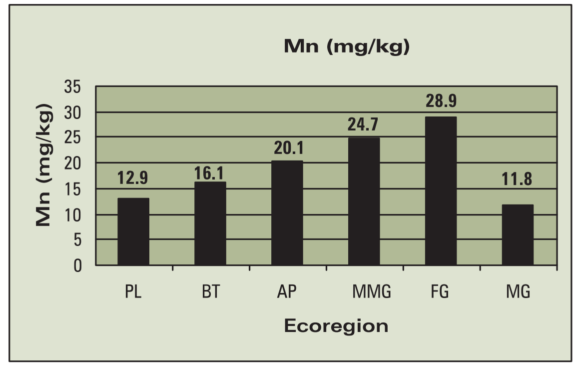

Figure 4.

Manganese level by ecoregion

Zinc

9 of the 14 samples deficient in zinc were from the Mixed Grasslands Ecoregion and had less than 2 per cent soil organic matter. Previous studies have identified zinc deficiency in beans and corn in this ecoregion.

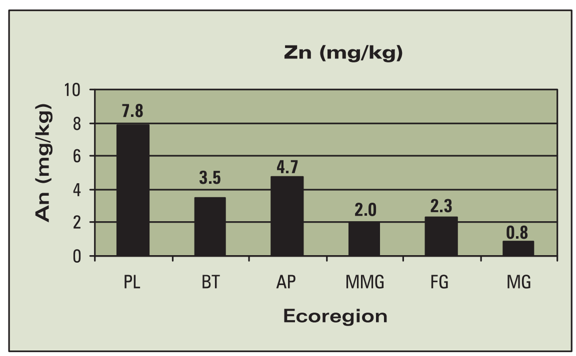

Figure 5.

Zinc level by ecoregion

C. Slope position trends

Extractable levels of all four micronutrients tended to increase from the upper to the lower slope position (Table 4). At some sites, this downslope increase was quite large, ranging from deficient at the upper slope to more than adequate at the lower slope.

Table 4.
Average micronutrient levels in topsoil samples by slope position

Slope Position	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)
Upper	0.8	79	15.0	3.0
Middle	0.8	97	17.6	3.3
Lower	1.0	147	18.6	5.3

Soil organic matter content also tended to increase downslope, indicating the strong influence of organic matter on micronutrient levels. It was not possible to determine if the downslope trends in organic matter and micronutrient levels occurred naturally or were caused by soil and crop management practices that accelerated erosion of the upper slopes.

D. Topsoil versus subsoil trends

The topsoil samples and subsoil samples had generally similar trends for the relationships of micronutrient levels to soil properties, ecoregion and slope position.

Concentrations of iron, manganese and zinc were generally somewhat higher in the topsoil than in the subsoil. The pattern for copper was more varied, with the subsoil concentrations lower in some cases and higher in others.

More Information

For more information on micronutrients and crop growth, contact a professional agronomist or see the following factsheets from Alberta Agriculture, Food and Rural Development: *Micronutrient Requirements of Crops in Alberta* (Agdex FS531-1), *Copper Deficiency: Diagnosis and Correction* (Agdex FS532-3) and *Minerals for Plants, Animals and Man* (Agdex FS531-3).

For copies of this and other fact sheets in the AESA Soil Quality Benchmark Sites factsheet series or for information on the AESA Soil Quality Benchmark Study, call Karen Cannon at (780) 422-4385.

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Implications for Field Management

- On soils with low to moderate organic matter levels, reduce the likelihood of iron, manganese and zinc deficiencies by using practices that increase soil organic matter, such as reducing tillage and applying manure to eroded knolls. Copper is an exception; applying of manure on eroded knolls can increase copper deficiency.
- Practices to decrease soil erosion can reduce both variability within fields and development of micronutrient-deficient areas.
- Copper and zinc are the micronutrients most likely to be deficient.
- Micronutrient deficiencies are not widespread in Alberta, but significant reductions in crop yield and quality can occur on some soils. Because symptoms of these deficiencies are easy to confuse with other problems such as salinity, herbicide injury and disease it is best to, test the soil before considering a micronutrient fertilizer application.
- Large differences in micronutrient levels occurred between upper and lower slope positions, so a composite soil sample from a field may not identify a deficiency. If you suspect a deficiency, collect samples on the field's upper slopes and other areas where the crop shows signs of a possible deficiency. Compare the micronutrient levels in these samples with those from areas where the crop looks healthy.
- If you do have a micronutrient deficiency, select crops and crop varieties less susceptible to the deficiency, or consider applying the appropriate micronutrient fertilizer in a test strip to assess its cost-effectiveness before trying a broader application.
- Toxic levels of the four micronutrients are uncommon in Alberta. However, they may occur under some circumstances: where soils are very acidic or where high rates of amendments with high micronutrient levels (such as municipal and industrial sewage sludges) have been applied.
- On acidic soils, watch for manganese toxicity.