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 (CaCO₃), 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 the 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.
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.**

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deficient</td>
</tr>
<tr>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>• soil with less than 7% organic matter</td>
<td>0.0 - 0.4</td>
</tr>
<tr>
<td>• soil with more than 7% organic matter</td>
<td>0.0 - 0.6</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0 - 2.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.0 - 0.5</td>
</tr>
</tbody>
</table>


**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.**

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Organic Matter (OM)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (Cu)</td>
<td>more clay, more Cu</td>
<td>more OM, higher pH, less Fe</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>more OM, more Fe</td>
<td>higher pH, less Mn</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>more OM, more Mn</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>more OM, more Zn</td>
<td></td>
</tr>
</tbody>
</table>
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 the 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

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

![Copper level by ecoregion](image1)

**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 (>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).

![Iron level by ecoregion](image2)

**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).

![Manganese level by ecoregion](image3)

**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.

![Zinc level by ecoregion](image4)

**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

<table>
<thead>
<tr>
<th>Slope Position</th>
<th>Copper (mg/kg)</th>
<th>Iron (mg/kg)</th>
<th>Manganese (mg/kg)</th>
<th>Zinc (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>0.8</td>
<td>79</td>
<td>15.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Middle</td>
<td>0.8</td>
<td>97</td>
<td>17.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Lower</td>
<td>1.0</td>
<td>147</td>
<td>18.6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

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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