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# Topographic Influences on Micronutrient Distributions in Saskatchewan Soils

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## Introduction

Recently, considerable interest in variable rate applications of agrochemicals (fertilizers, herbicides, pesticides) has been expressed by producers and researchers alike. In general, variable rate applications or precision farming, relies on one's ability to predict high or low fertility areas in a field that could influence crop yields. The producer can then manage these areas differently. For example, areas typically characterized by low soil fertility, such as eroded knolls, might be more heavily fertilized than the naturally more fertile depressional areas. Alternatively, moist depressional areas that tend to harbor more root and leaf diseases or higher weed populations could be sprayed with pesticides or herbicides independently of areas where incidences of these pests are typically low. In theory at least, the producer would save on input costs on a field by field basis.

Copper (Cu) and boron (B) are the two micronutrients generating the most interest; copper, because it is considered to be the most limiting micronutrient and boron, because of the increased production of high yielding crops with a high boron requirement. This study was conducted as part of a larger project investigating the overall potential for precision farming applications in Saskatchewan agricultural areas. The specific objectives of the micronutrient study were to examine the distribution of plant available forms of selected micronutrients in relation to topography and assess the probability of future micronutrient deficiencies developing in crops grown at the study sites. The results of this study are expected to have important implications regarding the application of variable rate technology with respect to the management of micronutrient fertilizers – particularly if the distribution of one or more micronutrients is found to be strongly influenced by topography. Though the 'precision farming' study as a whole included eight sites representing soils in the Black, Dark Brown and Brown soil zones of Saskatchewan, only four of the sites will be discussed here. Likewise, although five micronutrients (boron, copper, iron, manganese, and zinc) were measured at all eight sites, only copper and boron will be discussed in the present paper.

## **Material and Methods**

Sites were established at the Conservation Learning Centre (CLC) near Prince Albert (Moist Black), Hepburn (thin Black), Outlook (Brown) and Swift Current (Brown). Whereas the CLC, Hepburn and Swift Current sites involved dryland farming practices, the Outlook site was irrigated. The experimental area at each site was classified according to management unit: upper (knoll), mid-, and lower (depressional) slope positions. Upper slope positions were typically thin, dry Regosolic soils; soils in the mid-slope positions were well developed Chernozems; and soils in the lower slope positions were Gleysols that periodically experienced water logging. Whereas topographic analysis revealed that only the upper and lower slope positions were represented in the landscape at the CLC site, all three management units were represented at each of the other sites. At each site, six replicate blocks were positioned to span each of the management units (Fig. 1). Though the larger study involved various treatments of nitrogen and phosphorous fertilizer (randomly applied in strips within each block), only the treatment receiving the recommended rate of nitrogen fertilizer and no phosphorous fertilizer (1N, 0P) was sampled in each block for subsequent micronutrient analyses. Soils from each management unit were spring sampled at 3 depths: 0–15 cm; 15–30 cm; and 30–60 cm. DTPA-extractable Cu was determined according to the method developed by Lindsay and Norvell (1978). Plant available boron was determined using the protocol described by Bingham (1982).

A preliminary analysis of the data indicated that none of the micronutrients at any depth were normally distributed; i.e., they all had a high degree of skewness. Consequently, the data were analyzed using non-parametric procedures and only the median values are presented. Data were analyzed using the Friedman two-way analysis of variance by ranks.

## **Results and Discussion**

### ***Copper***

Copper is the micronutrient that is generally considered to be most limiting in western Canada. Copper deficiency can reduce grain yields directly, because of its role in chlorophyll production, protein synthesis and respiration and can also lead to indirect yield losses by increasing a plant's susceptibility to root, leaf and head diseases. The critical levels of soil copper used by Enviro-Test Laboratories Agricultural Services, Saskatoon (1999), set the marginal concentration range for copper at between 0.6 and 1.0 ppm (1.2 – 2.0 lb/ac). Soils with copper concentrations less than 0.6 ppm are considered deficient; soils with copper concentrations greater than 1.0 ppm are considered optimal. Toxic levels for copper are greater than 16 ppm (it should be noted that none of the soils considered in this study approached this level).

The Hepburn (Fig. 2A) and Swift Current (Fig. 3A) sites were fairly 'typical' sites for copper distribution. That is, concentrations of copper were lowest in the surface soil and

increased with depth in the soil profile. Based on the critical levels established by Enviro-Test laboratories (for soils sampled to a depth of 6 inches; i.e., 15 cm), soils at both the Hepburn and Swift Current sites would be considered marginal for copper concentration. Slope position had no effect on copper distribution at any of the depths.

Researchers in Alberta have established that the distribution of copper through the soil profile is more important for determining the probability of a deficiency occurring in a crop than are the values for surface soils (Penny et al., 1992). For example, a crop deficiency is far more likely to develop in a soil where copper levels are low throughout the soil profile than in a soil that has deficient concentrations in the surface horizon but with concentrations that increase deeper in the soil profile. Though in this example, copper concentrations in the surface horizon of both soils are characterized as being deficient (and hence test as requiring added copper fertilizer), only in the first case is the soil truly copper-deficient. That is, deficiency symptoms occur because roots growing deep into the soil profile as the crop matures during the growing season are unable to obtain sufficient copper from the soil. In the latter soil, copper concentrations in the subsurface soil are sufficient to meet the crop's demand as it matures throughout the growing season. Accordingly, increasing concentrations of copper in subsurface soils at both the Hepburn and Swift Current sites make it unlikely that copper deficiency would develop in the overlying crop. Indeed, there have been no reports of copper deficiency symptoms for any crop grown at either of these field sites.

The expression of deficiency symptoms in plants also can be affected by environmental conditions. For example, in soils with low concentrations of copper in the surface horizon, but which increase with depth, crops are more likely to exhibit deficiency symptoms during a growing season characterized by high precipitation. That is, because water is the main factor affecting root distribution, plant roots will tend to remain near the surface and not explore the deeper soils where copper is more abundant. In contrast, soils that are copper depleted throughout the soil profile are more likely to produce deficiency symptoms during a dry growing season. Even though copper distributions were generally unaffected by slope position, it may be that deficiencies are more likely to exhibit themselves in lower landscape positions, when surface soils test low for copper, as these areas tend to be wetter and therefore should be more prone to shallow rooting.

Outlook was the only site that showed a landscape effect for copper distribution ( $P = 0.03$  at 0–15cm;  $P = 0.009$  at 15–30 cm; and  $P = 0.135$  at 30–60 cm depths) with copper concentrations being greatest in upper slope positions at all depths (Fig. 4A). The soil characteristics responsible for this slope position effect were not determined. In the lower and mid-slope positions copper concentrations in the surface 15 cm were at the low end of the marginal range, indicating a possibility of deficiency developing in the future or in high copper utilizing crops such as wheat. Researchers in Alberta determined that crops grown on marginally copper deficient soils may have losses of 20% or more in grain yield while not showing visual symptoms of a deficiency (Solberg et al., 1998). However, as was the case at Hepburn and Swift Current, copper concentrations increased with depth at Outlook, making the probability of crop deficiencies for copper unlikely – except possibly during a wet growing season.

Concentrations of available copper in soils from the Conservation Learning Centre indicated that these soils were marginal to deficient (Fig. 5A). Copper concentrations were the lowest at the surface and increased only slightly with depth. In addition, there was no significant effect of slope position on copper concentration. Of the four sites examined, the Conservation Learning Centre is the most likely site to develop deficiency conditions in crops. In mineral soils, organic matter content and soil pH are the soil factors that have the most affect on copper availability – copper is strongly bound to organic matter and its availability is reduced as the pH increases to 7 and greater. However, Solberg et al. (1998) reported that copper deficient mineral soils in Alberta typically had a pH range from 5.8 to 6.8. Consistent with this, the soils south of Prince Albert, Saskatchewan where the Conservation Learning Centre is located are relatively rich in organic matter (5.5–6.4% in the Ap horizon; Rostad et al., 1993) and have pH values between 6.6 and 7.5 (Rostad et al., 1983) making this and other areas of the Thick Black soil zone more prone to developing copper deficiencies than thinner, drier, less productive soils in the Thin Black, Dark Brown and Brown soil zones.

### ***Boron***

Concern with boron deficiency is on the rise in western Canada primarily because of the increased production of high yielding crops with high boron requirements such as canola and alfalfa. Because of the difference in boron requirements exhibited by different crops, two sets of guidelines are used by Enviro-Test Laboratories Agricultural Services, Saskatoon (1999). The marginal range for crops with low boron requirements (e.g., cereals) is 0.25–0.50 ppm (0.5–1.0 lb/ac). Concentrations below this range are deficient and concentrations above this range are considered optimum. The marginal range for crops with high boron requirements (e.g., canola) is 0.35–0.60 ppm (0.7–1.2 lb/ac). As with copper, all values are based on a 0–15 cm soil sample.

The Swift Current (Fig. 3B) and Outlook (Fig. 4B) sites were fairly ‘typical’ in terms of boron distributions; i.e., in both cases there was an accumulation of boron in the lower slope positions. However, whereas at Swift Current there was a significant slope effect at all sampling depths ( $P = 0.042$ , 0–15 cm;  $P = 0.030$ , 15–30 cm;  $P = 0.042$ , 30–60 cm), at Outlook this effect was significant ( $P = 0.030$ ) only in the surface 0–15 cm layer. Boron is readily soluble in water and should move with the flow of water through the landscape. Thus, because the lower slope positions represent catchment areas in the field and periodically experience water logged conditions, boron would be expected to accumulate in these areas. Similarly, boron concentration would be expected to increase with depth in the soil due to downward water movement through the soil profile. In contrast to this expectation, it was generally observed at both Outlook and Swift Current, that the highest boron concentrations occurred in the surface soil and decreased slightly with increasing depth.

Boron concentrations at Outlook (Fig. 4B) were in the high-marginal to optimal range, indicating a very low probability for boron deficiency developing – regardless of the crop grown. At Swift Current (Fig. 3B), however, boron concentrations in the mid- and upper slope positions tended to be in the deficient range, especially deep in the soil profile. Based on these results, the Swift Current site is a likely candidate for the future

development of a boron deficiency, especially in crops that require large amounts of boron.

The Conservation Learning Centre site (Fig. 5B) showed the same tendency for boron to accumulate in the lower slope positions, particularly in the upper 30 cm of the soil profile ( $P = 0.014$  at 0–15 cm and  $P = 0.014$  at 15–30 cm). Concentrations deep in the soil profile were not affected by slope position. All concentrations were in the optimal range, so that despite low boron concentrations in the upper slope positions, it is very unlikely that any boron deficiency would show up in a crop grown at this site.

The Hepburn site showed a tendency for boron to accumulate in the mid and upper slope positions (Fig. 2B). However, a tremendous amount of variability occurred at this site and although the slope effect appears quite strong it is not statistically significant. Boron distributions at this site are quite erratic, with some concentrations in the deficient range but most in the optimal range. This site, in particular, demonstrates the extreme patchiness that is often associated with micronutrient distributions (Singh et al., 1984).

## Summary

The general lack of a landscape effect on copper concentrations suggests that (i) it is not possible to predict areas of low copper fertility based on slope position and (ii) the application of copper fertilizers would not benefit from variable rate application technologies. Furthermore, at the one site (Outlook) where copper distribution showed a distinct landscape effect, concentrations of plant available copper were generally sufficient to meet the needs of any crop. Furthermore, three of the four sites tested showed increasing concentrations of copper with depth, indicating that copper deficiency is unlikely to develop in these soils. However, one site (the Conservation Learning Centre) did appear to be susceptible to developing copper deficiency in the future. Concentrations of plant available copper were fairly low at this site and there was no significant increase in copper concentration with depth. The low copper concentrations are consistent with soil properties common to soils in the Thick Black soil zone.

Except at the Hepburn site, boron distributions reflected the flow of water through the landscape; i.e., boron tended to accumulate in the lower slope positions. Interestingly, it did not accumulate deep in the soil as would be expected with the downward movement of water through the soil profile. In general, although the landscape effect on boron distribution was statistically significant, it appears to be of little consequence; i.e., despite the landscape effect, differences in the concentration of plant available boron were minimal. Consequently, it is unlikely that slope position could be used to accurately assess the boron fertility requirements of a field. Only at the CLC site did the landscape effect in the surface 0–30 cm appear strong enough to allow a general prediction of boron fertility; however, at this site all boron concentrations were well within optimal ranges. Of the four sites evaluated, the Swift Current site is the most likely site to manifest a boron deficiency in a crop, with deficiencies probably occurring in the mid and upper slope positions before the lower slope positions. The Hepburn site did not show any

slope effects for boron distributions, and exemplified the extremely erratic and patchy nature of boron distributions across a landscape.

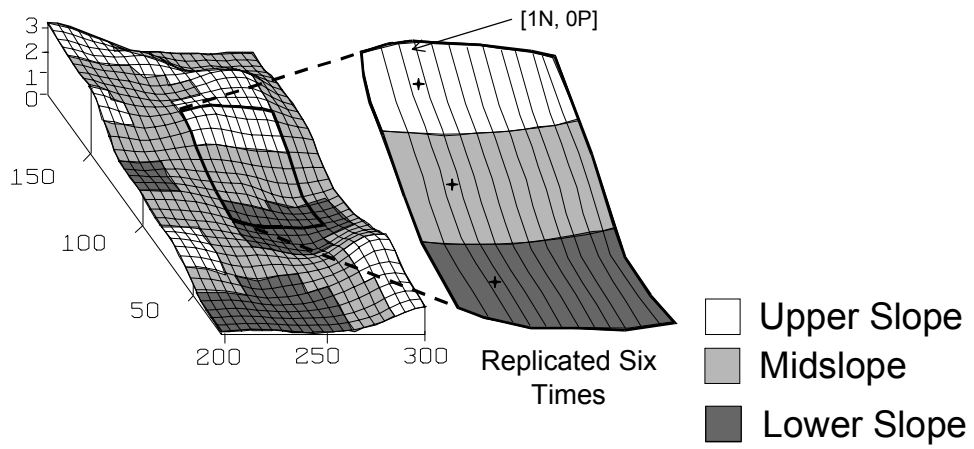
### **Acknowledgements**

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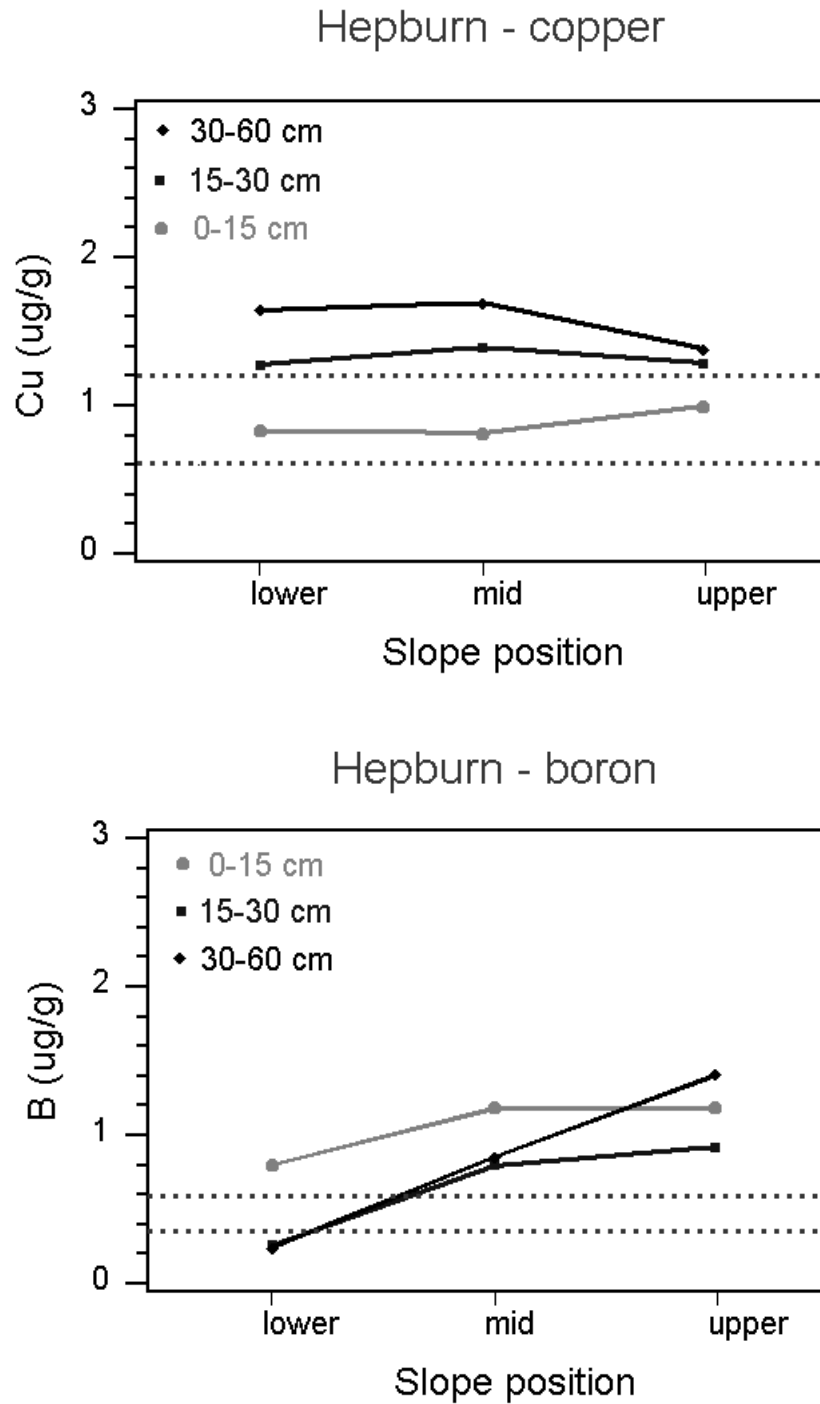
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# Sampling Design

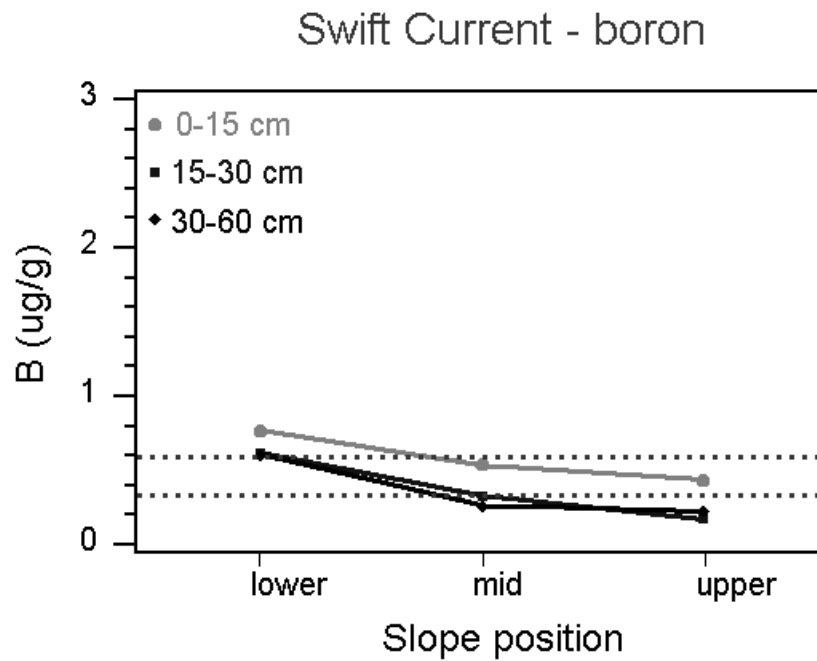
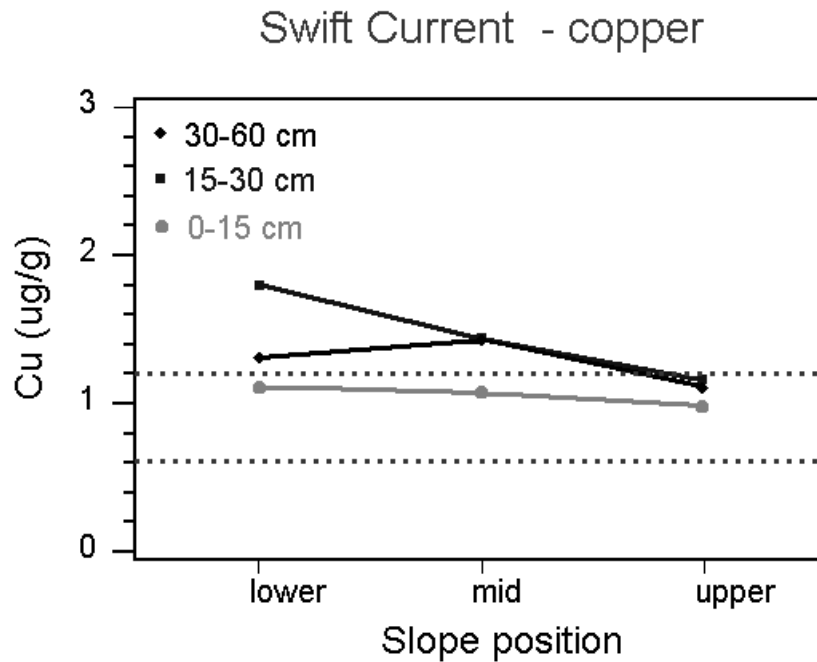


**Fig. 1.** Design for micronutrient soil sampling at the field sites.

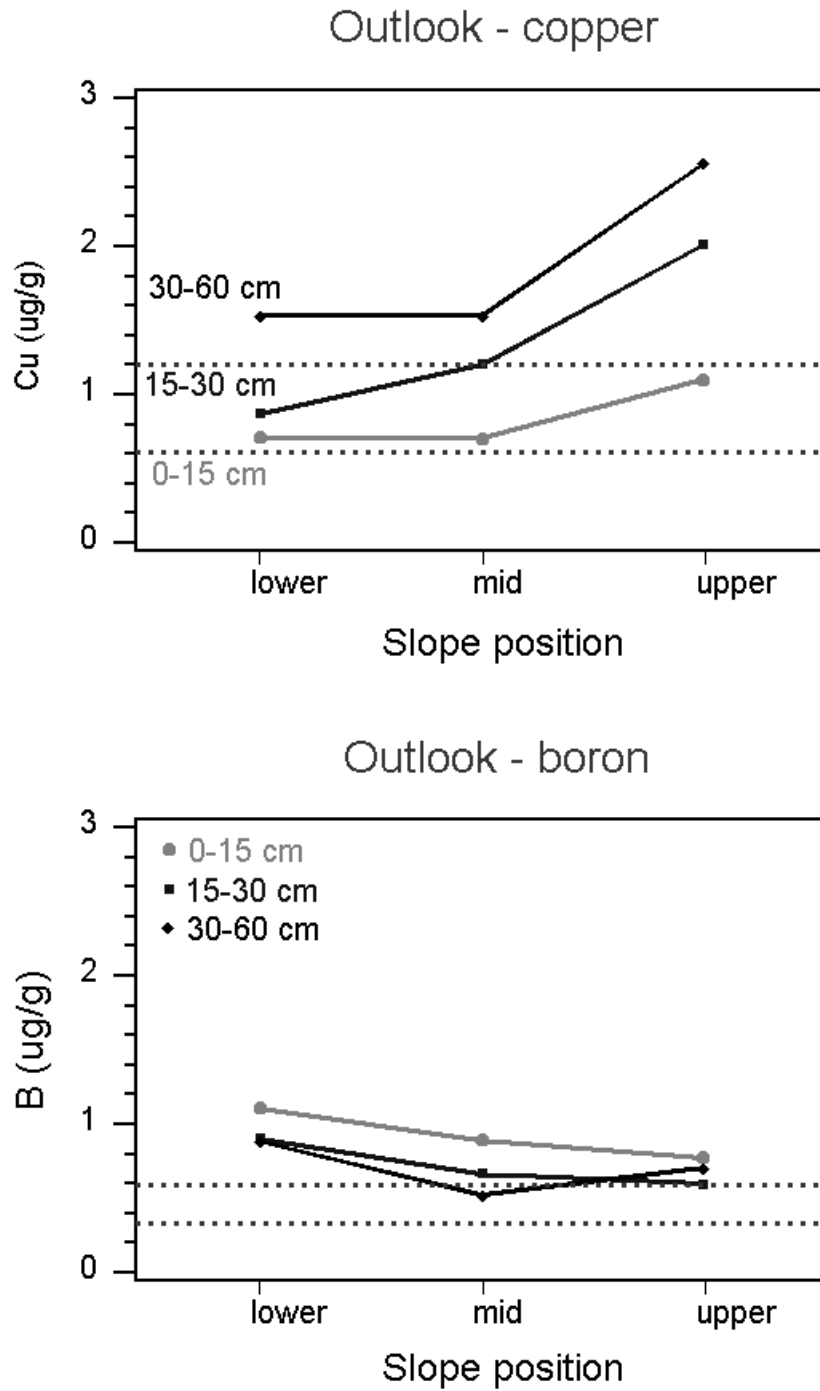


**Fig. 2.** Distribution of copper (top) and boron (bottom) according to slope position at the Hepburn site. Dotted lines on the graph indicate the range of marginal micronutrient concentrations. Concentrations below the lower line are deficient, and above the upper line are optimal. Boron ranges indicated are for high boron using crops.

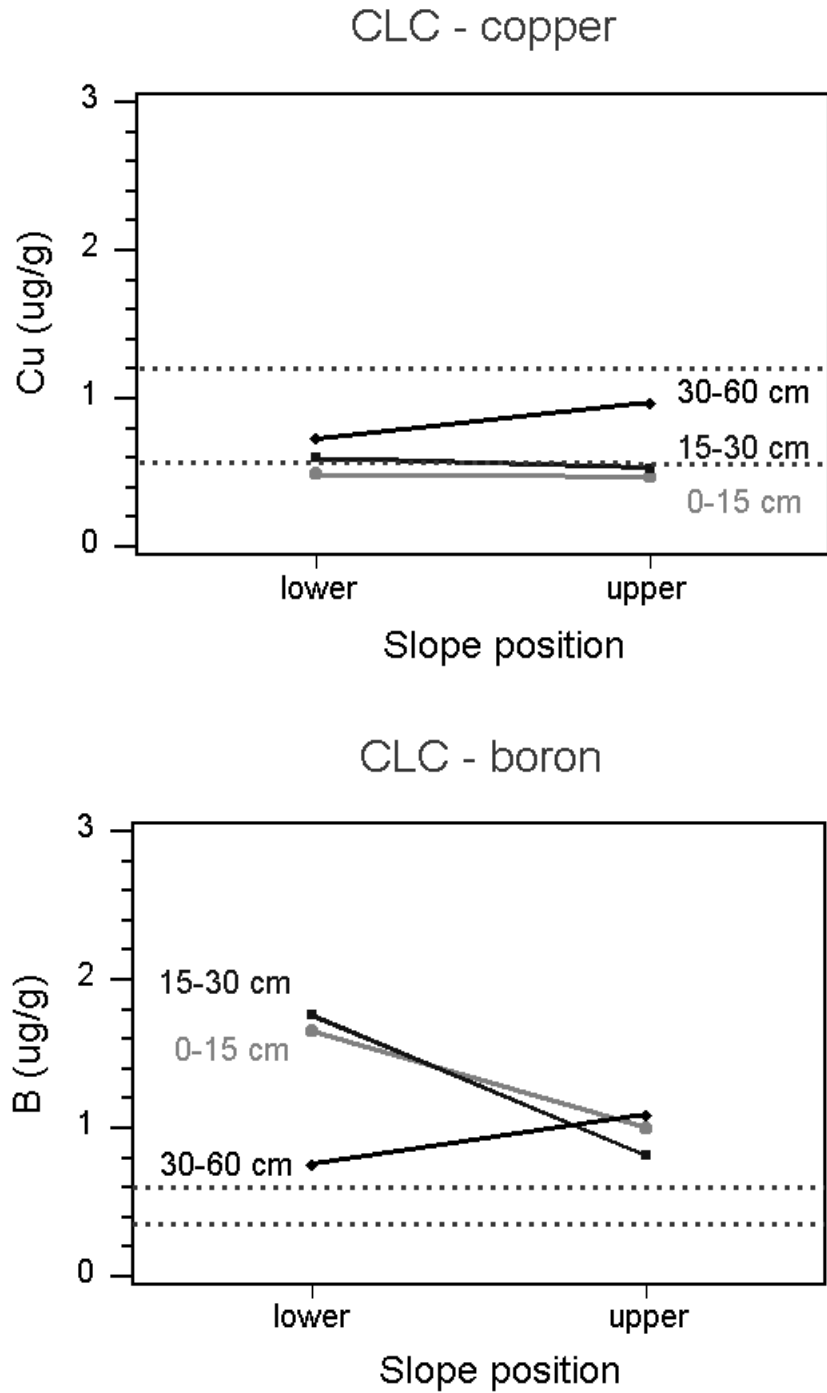




**Fig. 3.** Distribution of copper (top) and boron (bottom) according to slope position at the Swift Current site. Dotted lines on the graph indicate the range of marginal micronutrient concentrations. Concentrations below the lower line are deficient, and above the upper line are optimal. Boron ranges indicated are for high boron using crops.



**Fig. 4.** Distribution of copper (top) and boron (bottom) according to slope position at the Outlook site. Dotted lines on the graph indicate the range of marginal micronutrient concentrations. Concentrations below the lower line are deficient, and above the upper line are optimal. Boron ranges indicated are for high boron using crops.



**Fig. 5.** Distribution of copper (top) and boron (bottom) according to slope position at the Conservation Learning Centre site. Dotted lines on the graph indicate the range of marginal micronutrient concentrations. Concentrations below the lower line are deficient, and above the upper line are optimal. Boron ranges indicated are for high boron using crops.

## **Key Topic Words**

Boron, Copper, Micronutrients, Topographic distribution,