SOIL MICRONUTRIENT PROBLEMS AND RESEARCH IN WESTERN CANADA

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Abstract

Micronutrient deficiencies have been recorded in a few Western Canadian soils. This paper reviews the published work on zinc, manganese, copper, iron, boron and molybdenum in Western Canadian soils and plants. Suggestions are made for procedures that could be employed by soil testing laboratories and research agencies to identify deficient soils.

1. Introduction

Knowledge of micronutrient deficiencies in Western Canadian soils, and of the effectiveness of plant and soil tests in identifying them, is still very sketchy. However, certain deficiencies have been observed and others can be expected as cropping continues without micronutrient fertilization.

Although several soil and plant tests for micronutrients are offered in both public (Table 1) and private soil testing laboratories, accurate criteria for their interpretation under Western Canadian conditions are largely lacking. Published sufficiency/deficiency levels established elsewhere are commonly used when required, with isolated cases of locally determined criteria (Table 2). Most of the research work to date has attempted to determine the validity of critical levels for micronutrient tests under local conditions, and identify deficient soils. The elements of concern have been boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), and zinc (Zn).

2. Western Canadian Research and Publications

2.1 British Columbia

The B.C. Leaf Analysis Service publishes suggested concentration ranges for B, Fe, Mn, and Zn in fruit tree leaves, grape petioles, and tomato and cucumber leaves (Tree Fruit Production Guide for Interior Districts 1981, Grape Production Guide 1981, Leaf Analysis for Greenhouse Vegetable Crops 1977; B.C. Ministry of Agriculture and Food). For these crops, foliar analysis and foliar fertilizer application are more common than soil analysis and soil fertilization with micronutrients. Ashby (1969) considered the usefulness of soil analysis to be limtied by the deep rooting zone of trees and the lack of good availability indices for most micronutrients except for hot water soluble B. The B.C. provincial laboratory currently tests soil for B only (Table 2), and suggests that B fertilizer be either applied to the soil or as a foliar spray.

Table 1. Micronutrient analytical methods in use in soils laboratories in Western Canada

Laboratory	Extractant - available micronutrients: Zn, Fe, Mn, Cu	B	Mo	Plant analysis, digestion[6]	Elemental determination (in extract or digest)
British Columbia Soil Testing Laboratory	DTPA[1]	Hot water[2]	-	$HNO_3/HClO_4$	ICPS[7] soil B-azomethine-H colorimetry (mineral soils), or circumin (organic)
Alberta Soil and Feed[9] Testing Laboratory (A.S.F.T.L.)	DTPA	Hot water	-	Cu, Zn, Se - $HNO_3/HClO_4$ others - dry ash, acid leach	ICPS
Agriculture Canada, Lethbridge, Alta.	DTPA	Hot water[3]	-	Fe, Mn, Zn - $HNO_3/HClO_4$ Co, Cu, Al - dry ash, acid leach	Atomic absorption B - azomethine-H colorimetry
Saskatchewan Soil Testing Laboratory (S.S.T.L.)	DTPA	NH_4OAc[4]	Anion exchange resin[5]	$HNO_3/HClO_4$ B - dry ash with CaO, acid leach	Atomic absorption B - azomethine-H colorimetry Mo - with KSCN; colorimetry
Manitoba Provincial Soil Testing Laboratory	DTPA	-	-		

[1]Lindsay and Norvell (1969, 1978); B.C. does not presently offer DTPA test, but plans to.
[2]Method developed by M.K. John, H. Chuah, and J. Neufeld; unpublished.
[3]Gupta (1979).
[4]Gupta and Stewart (1975).
[5]Bhella and Dawson (1972), modified.
[6]Details of methods may vary among labs and elements.
[7]Inductively coupled plasma spectroscopy.
[8]Wolf (1971).
[9]A plant Se test is available: $HNO_3/HClO_4$ digestion and fluorometric determination.

Table 2. Criteria used in interpretation of micronutrient soil tests in provincial soils laboratories in Western Canada[1]

Element	Critical level (lbs./ac in soil of 0-6" depth) S.S.T.L.	Manitoba	B.C.
Cu	.40	.4-.8 (marginal range mineral soils only)	
Fe	5-9 (marginal range)		
Zn	1.0 1.0-2.0 - marginal for high phosphate levels and irrigation	1.0-2.0 (marginal range)	
Mn	2.0		
B	0.7 (> 7.0 - toxic)		<.40 VL .41-1.0 L 1.01-2.0 M >2.0 H (critical level 0-2.0 depending on crop B requirements)
Mo	0.10 (> 1.3 - toxic)		

[1]Using extract stated in Table 1.

Other micronutrients should be foliar-applied only. Recommendations are based on crop B requirements as well as soil levels. The origin of soil and plant criteria for micronutrient recommendations in B.C. is unclear, as records of field correlations were not available. However, the only extensive long-term use of micronutrient fertilizers has been in B.C. fruit crops. John (1972, 1974) studied extractable soil Zn and oat and corn Zn uptake from B.C. soils, but did not identify soils on which the crop yields were limited by Zn availability.

Lowe (1978) surveyed Cu levels in the Fort Fraser-Vanderhoof area, using diethylenetriaminepentaacetic acid (DTPA), ethylenediaminetetraacetic acid (EDTA), and hydrochloric acid (HCl) extracts.

DTPA was considered the most appropriate extractant for the near-neutral soils encountered. Only coarse textured soils had DTPA-Cu and -Zn levels below 0.3 and 1.0 ppm respectively, marginal levels by most criteria. Alfalfa tissue samples from these soils were low in Cu but not Zn based on U.S. criteria. Soils with less than 0.7 ppm DTPA-Cu produced bromegrass with undesirably low Cu content (< 4 ppm) for forage use.

2.2 Alberta

Little if any work has attempted to establish local criteria for micronutrient recommendations in Alberta. The provincial laboratory uses published criteria (mainly from Western U.S. states) in interpretive work.

Dudas and Pawluk (1977) surveyed the heavy metal content of some Alberta soils and cereal crops. Some low plant Cu, Mn, and Zn levels were found, but these were not related to HCl-extractable soil levels. Low Se soils have been identified, based on grain and forage Se levels (D.L. Massey and P.J. Martin, Selenium Soil-Plant Animal Relationship. Agri-Science. Plant Industry Division, Alberta Department of Agriculture). Selenium is not essential to crop growth, though it is required by animals and can be both toxic and deficient.

2.3 Saskatchewan

The Saskatchewan Soil Testing Laboratory also uses interpretive criteria based mostly on published American work (Table 2).

A survey of micronutrients in wheat, oats, and barley variety trials throughout Saskatchewan was conducted in 1966 and 1967 (Stewart 1969). Plant micronutrient levels were related to those in the soil extractable with HCl, NH_4Ac, and EDTA-$(NH_4)_2CO_3$, and to other soil properties. Generally, plant levels did not correlate well with concentrations in soil extracts ($r<0.6$). Some relationships were shown between soil properties and micronutrient cations in certain extracts, the chelate extractant being most consistent. Multiple regression analysis related plant micronutrient levels to other soil properties as well as levels in extracts. Coefficients of determination (r^2) were up to about 0.7, for Cu and Zn in barley and wheat, showing that consideration of soil properties may be beneficial in interpretation of micronutrient soil test data. Similar work related the Zn content of cereals to soil Zn extractable by NH_4Ac, DTPA, and EDTA, with DTPA-Zn giving the highest correlations (Stewart and Tahir 1971). Since chelate extractable Zn was predictable from soil survey information, the use of such data in prediction of possible Zn deficiency areas was suggested in areas where soils are derived from relatively uniform parent material. There was evidence that the critical Zn level in oats was less than the generally accepted value of 20 ppm.

Boron in wheat but not in alfalfa was related to hot water soluble B in an early greenhouse study using saline and nonsaline soils of southeastern Saskatchewan (Werkhoven 1964). Addition of B fertilizer did not affect yields. Gupta and Stewart (1975) found NH_4Ac extractable soil B to be as good an indicator of plant-available B as hot water soluble B was. The former was chosen for Saskatchewan Soil Testing Laboratory use because it was more convenient and reliable analytically. However, deficiency levels for the NH_4Ac test were estimated only from published hot water test levels and the relationship between the amounts of soil B extracted by the two tests, so locally derived critical levels were not established. Procedures for automated determination of B in solutions using azomethine-H were published (Gupta and Stewart 1978).

Copper deficiencies in cattle in eastern Saskatchewan prompted a survey of Cu and Mo status of pastures in that area in 1976 (Stewart and Racz 1977). DTPA-Cu (0-15 cm depth) correlated reasonably well with plant Cu, but plant Mo was unrelated to $(NH_4)_2CO_3$ extractable soil Mo. DTPA-Cu did not predict plant Cu at all in the second year of the study. This was attributed to much wetter growing conditions in the second year (Stewart et al. 1979). Under growth chamber conditions DTPA-Cu and anion exchange resin extractable Mo were highly correlated with the corresponding levels in bromegrass ($r = .86$ and $.84$, respectively). Thus the value of the two tests was supported, but critical levels were not established because yields were not increased with Cu or Mo fertilizers on any of the soils used. The Cu/Mo problem in cattle feeds was also shown in northwestern Manitoba (Lillie and Drysdale 1976). Doyle and Fletcher (1975) found plant Mo to be unrelated to total soil Mo in western Manitoba. Although correlations between plant and total soil micronutrient contents are rarely very good, some utility of geochemical surveys in delineating regions of possible micronutrient problems has been suggested (Doyle and Fletcher 1979).

A survey of the Mn content of oat leaves in Saskatchewan and Manitoba showed a clear relationship of the parameter to DTPA extractable soil Mn (Martens et al. 1977). Critical levels were not established, though many Manitoba and a few scattered Saskatchewan sites had less than 15 ppm Mn in oat tissue, the level at which gray speck disease symptoms appear.

In general, Saskatchewan studies have shown the existing soil micronutrient tests to have some validity, though success has been inconsistent. Regular soil survey data may assist in delineating soils with potential deficiencies. As present deficiencies have not been confirmed, local plant or soil criteria for their identification have not been derived.

2.4 Manitoba

Micronutrients, Zn and Cu in particular, have been somewhat more extensively studied in Manitoba. Thus, some local criteria for the established micronutrient tests have been developed, and relative effectiveness of forms and placements of fertilizers has been investigated. Copper deficiency on an organic soil, as indicated by response of onions and carrots to applied Cu, has been known for almost 20 years (Campbell and Gusta 1966).

Racz and Haluschak (1970) and Smid and Spratt (1974a, b) looked at nutrient and fertilizer interactions in selected soils. Several treatments and interactions affected plant nutrient levels, especially under growth chamber or nutrient culture conditions and when phosphorus (P) was a variable. However, yields were not affected by micronutrient levels or applications. There was evidence that the accepted critical level for Zn in corn of 20 ppm was too high under conditions used (Smid and Spratt 1974b), but also that certain soils were or could become deficient in Zn for optimum production. A survey of Manitoba corn crops in 1974-75 indicated that a large proportion of them were Zn deficient based on American criteria (Sadler and Fehr 1975). Bailey (1976) reported fababean yield increases due to Cu and Mo applications in certain soils, though the data did not appear conclusive.

In growth chamber studies with Manitoba soils, Cu and Zn sulfates were most effective when mixed throughout the soil. Critical Cu and Zn levels in six week old barley shoots were 5.2 and 12.5 ppm, respectively (Akinyede 1977). The Zn level for seven week old black-bean shoots was 13.5 ppm (Hedayat 1977).

Loewen-Rudgers et al. (1978) found that the critical DTPA-Cu soil level for barley was at least 0.56 ppm, since barley yield on a soil with that Cu level responded to Cu fertilization in the field and growth chamber. However, soils with lower DTPA-Cu levels were used in the following two years but responses were not obtained. They also reported that the chelate Na_2Cu-EDTA was five times as effective as $CuSO_4$ in increasing Cu uptake by barley. Large cereal yield responses to Cu fertilization occurred on organic soils in 1978. Barley took up Cu most efficiently, so was most resistant to deficiency. Cu deficiency was considered likely to occur on organic soils, but was still in question on sandy mineral soils.

In a greenhouse experiment critical plant and DTPA soil Zn levels were 13 and 1.3 ppm, respectively, for eight-week old flax (McGregor 1972, as cited in Loewen-Rudgers et al. 1978). As with Cu, yield response to Zn has been inconsistent. For example, a blackbean yield response to Zn addition occurred in one year on two high-lime soils with levels of 1.0 and 1.4 ppm DTPA-Zn, but not in the two following years when DTPA-Zn was lower. Corn did not respond on soils with DTPA-Zn levels of 0.7 and 1.1 ppm. Despite DTPA-Zn levels ranging from 0.3 to 1.2 ppm in a clay laom soil, wheat, oats, barley, flax, and rapeseed in the field did not show a yield response to added Zn during three years. On a similar soil with 0.45 ppm DTPA-Zn, beans responded to Zn fertilization in the greenhouse, while buckwheat and rapeseed did not. Barley benefitted from added Zn at DTPA soil levels up to 1.0 ppm. Chelated Zn (e.g. Na_2Zn-EDTA) was more efficient (2.5x) than zinc sulphate ($ZnSO_4$), and $ZnSO_4$ was used more effectively when mixed throughout the soil rather than banded for most cereal crops. With barley, however, seed placement was effective, even if $ZnSO_4$ granules were used. It was estimated that Zn deficiency was unlikely to occur in Manitoba cereal crops, but there was a possibility that it could occur in more susceptible crops.

Copper and zinc critical levels were estimated from field and growth chamber studies over the past few years. Less than 10 ppm Zn in blackbean tissue at early flowering indicated a deficiency. The critical level for Cu at early pod formation in the same crop was 3.8 ppm in the plant and 0.3 ppm DTPA-Cu in the soil (McKenzie 1979). The order of decreasing tolerance of plants to low soil Cu was rapeseed-barley-oats-wheat-flax, with critical plant levels of 2.7, 3.7, 2.5, 4.9, and 3.5 ppm, respectively, 43-52 days after seeding (McAndrew 1979). Field studies indicated a critical soil DTPA-Zn level of less than 0.8 ppm for cereals and oilseeds, and based on this value it was thought that a Zn deficiency is not likely to occur in oilseed and cereal crops in most Manitoba soils. In organic soils, however, a critical DTPA-Cu level of 1-2 ppm was suggested. Incorporation of Cu and Zn sources after being sprayed on the soil in solution was an effective form of supplying these elements.

The importance of Cu application to organic soils, especially for wheat, was also indicated from work carried out by Tokarchuk et al. (1979). In this work it was noted that barley, wheat, and rapeseed grown on organic soils also had low Mn levels, and responded to Mn foliar sprays. However, these results were contrary to earlier work in which oats did not benefit from $MnSO_4$ applications (Loewen-Rudgers et al. 1978). Similarly, several tests with foliar applications of $FeSO_4$ to beans, soybeans, and flax showed no Fe deficiencies.

Tests carried out the following year again showed wheat and barley to be responsive to Cu addition in organic soils (Reid and Racz 1980). Boron fertilization increased barley yield at one site. Seed-placed Mn raised tissue Mn levels more so than when broadcast, whereas foliar applications were ineffective. Year to year variations in yield and tissue minor element levels were emphasized.

In Manitoba then too, micronutrient soil tests have proven useful but not consistent. Known deficiencies (for Cu in particular, but also Zn) have permitted study of micronutrient critical levels in plants and corrective measures. Critical soil and plant levels established elsehwere have not proven to be reliable indicators of deficiencies.

3. Micronutrient Deficiencies in United States Areas Bordering Western Canada

American and world literature is not reviewed here in detail as comprehensive texts exist (Mortveldt et al. 1972, Aubert and Pinta 1977, Kubota 1980), but a few survey results from Northwestern and Great Plains regions of the United States will be noted. Micronutrient deficiencies were surveyed by the Soil Testing Committee of the Soil Science Society of America (1965) from experimental station data. Boron deficiencies were recorded for legumes and tree fruits in Oregon; for tree fruits in central Washington and alfalfa in light or levelled soils of that state; for alfalfa and fruit in sandy granite soils of Montana; for legumes in Idaho; for sugar beets on sandy South Dakota soils; and for alfalfa on acidic Minnesota soils low in organic matter. Insufficient Fe was available to legumes on alkaline Montana soils; to flax and soybeans on poorly drained South Dakota soils with high organic matter, salts, and pH; to flax and soybeans on high-lime Minnesota soils; and to fruits and ornamentals in certain soils of most states. Barley and fruit trees from parts of Oregon had low Mn levels. Eastern Washington soils were low in Mo for legume growth. All the above states plus North Dakota had areas of Zn deficiency, mainly with reference to corn but also for fruits, potatoes, and legumes. Calcareous soils, especially if eroded or levelled, were most often involved.

The U.S. Dept. of Interior Geological Surveys reported the total content, extractability, and native plant uptake of elements in Northern Great Plains soils. Correlations between plant uptake and chemical extractability from soil varied widely with species, even cultivars, and soil factors (Severson et al. 1977). Though no extract gave close relationships ($r^2 < 0.50$), elements in DTPA extracts of ground soil best related to plant availability. Plant uptake of elements was more often related to pH than to other soil properties. When plant element contents were related to soil extractable elements and other soil properties, DTPA extracts of unground soils were most efficient. Even this technique predicted levels of plant nutrients of concern here only poorly when only commonly measured soil properties were employed. Soil grinding affected amounts of Fe, Mg, and Mn extracted by DTPA. Results of later work were similar (Gough et al. 1978).

4. Potential Problems in Western Canada

Based on analysis of the areas or conditions under which problems may exist (Aubert and Pinta 1977, Kubota 1980), as well as results of local and other research, the micronutrient deficiencies most likely to occur or develop in Western Canada are:

i) inadequate availability of soil B, Mg, Mn, Fe, and Zn for fruit culture in B.C., and also for these crops in the Prairie Provinces, depending on the degree to which the soil is sandy, acidic, and leached;

ii) B deficiencies in sensitive crops (root crops, horicultural crops, alfalfa, crucifers) most likely where soils are sandy or organic, acidic or calcareous, and leached, as along parts of the northern limits of cultivation;

iii) Cu-deficient horticultural crops, alfalfa, and wheat on organic soils, particularly those underlain by calcareous material;

iv) low Mo availability for growth of crucifers on very light, leached, acid soils only;

v) scattered occurance of Mn deficiency in poorly drained non-acid soils in some years, especially for oats, legumes, and horticultural crops;

vi) Fe unavailability to many horticultural crops on alkaline soils which are sandy or organic;

vii) Zn deficiency for corn and legumes on calcareous soils, especially where the soils are eroded or have been graded; also for specialty crops, as in the fruit-growing areas of B.C.;

viii) deficiencies of Zn and Cu, and possibly B and Mo, for crops with high requirements for these, on light irrigated soils.

Micronutrient toxicity is unlikely to limit crop growth in soils in Western Canada, though soils with high Mo and Se availability may produce feeds with toxic levels of these elements for cattle.

Of the above possible deficiencies, only a few have been clearly shown to occur in the field by yield increases due to micronutrient fertilization. Even in B.C. fruit production deficiencies are diagnosed largely on the basis of symptomology rather than yield or growth measurements. However, these parameters are difficult to measure in perennial tree fruits, and the industry is considered dependent on regular micronutrient use (Ashby 1969). Other confirmed yield responses are limited to applied B for B.C. alfalfa, corn, and some vegetables (D.A. McCoy, B.C. Soil Testing Lab., personal communication), and Cu for several crops on organic soils of Manitoba and coastal B.C. Legumes on calcareous Manitoba soils have given yield responses to Zn in the growth chamber but few reports document yield responses in the field. Plant nutrient uptake responses to micronutrient fertilization can often be obtained while yield is unaffected. Yield responses in the field are notoriously inconsistent from year to year, and highly crop and soil specific. Copper deficiency symptoms in cereals on organic soils in Saskatchewan have been observed, but not confirmed (J.L. Henry, Soils Dept., Univ. of Sask., personal communication).

5. Suggested Strategy for Soil Testing Laboratories and Research

In the short term, research and development imperatives are simple in light of the early stage of micronutrient research in Western Canada. Sampling and laboratory methods must initially be standardized and checked for accuracy, analytical suitability, and contamination problems. Extensive field surveys are then required to identify areas and soils where deficiencies exist.

Micronutrient analytical methods are already reasonably consistent across Western Canadian public laboratories (Table 1). All use Lindsay and Norvell's (1978) DTPA extraction for the micronutrient cations Cu, Fe, Mn, and Zn. The test is well-accepted, theoretically sound, and suited to the calcaerous soils in which some deficiencies are most likely to occur. Generally, micronutrient cation uptake by plants has correlated as well or better with the cations in DTPA extracts than with those in other extracts. Until more soils with known micronutrient deficiencies are identified, the usefulness of the DTPA extraction as a soil testing tool cannot really be tested locally, though there appears to be no good argument against its use. DTPA with NH_4HCO_3 for simultaneous extraction of micronutrient cations, P, Ca, Mg, Na and K (Soltanpour and Schwab 1977) might be employed if high priority is given to large-scale micronutrient surveys based on farm soil samples entering public laboratories and plasma-arc instruments are used for analyses. However, disadvantages to this method include the instability of the extracting solution, use of carbon black, and the need for recalibration of results (for P and micronutrients in particular). The advantage of Soltanpour and Schwab's method is that it can determine both macro and micronutrient fertilizer elements with the exception of N and possibly S with one extraction and analyze them simultaneously in a few seconds. Obviously the economics of this method coupled to the availability of ICPS instruments means that all laboratories should be comparing methods for $NaHCO_3$ or NH_4Ac extractable P, Ca, Mg, K and Na, and DTPA-Zn, Cu, Mn and Fe, with the DTPA-NH_4HCO_3 method. This would allow them to make a decision on using DTPA-NH_4HCO_3 extractions based on their own data.

Careful control of extracting conditions is essential if contamination is to be avoided. Details of sample preparation and extraction must be precisely duplicated for results of the DTPA test to be consistent among laboratories. For example, eight American state labs which analyzed the same nine soil samples reported up to six-fold differences in Cu and four-fold differences in Zn for identical samples (Lamborn 1971, as cited in Viets and Lindsay 1973). Extraction is affected by time and force of soil grinding, type and speed of shaker, filtering time, type of extraction vessel (Soltanpour et al. 1976), shaking time, DTPA concentration, pH, temperature (Lindsay and Norvell 1978), and wetting and drying (Khan and Soltanpour 1978). Since only a few labs are involved in Western Canada it should be possible to standardize the DTPA test in every detail so that research results have more general applicability, an alternative considered impractical by Soltanpour et al. (1976) on a larger scale. The benefits of standardization of techniques and occasional sample exchanges among labs of course apply to other analyses as well.

The value of standardization of the B test is debatable, since B deficiencies are not likely to be of much significance outside of B.C. The NH_4Ac extraction procedure (Gupta and Stewart 1975) may be easier to duplicate among laboratories, but is less well known and is not backed up by the volume of research recorded using the hot water extraction. Hot water extraction methods presently in use vary somewhat.

Standardization of the Mo availability test is not a problem, as only the Saskatchewan provincial lab offers such a test. The method used, employing an anion exchange resin, is theoretically and analytically satisfactory (Reisenauer et al. 1973) but is quite time consuming. This test as well as the more popular acid ammonium oxalate extraction has sometimes been reported to correlate with yield or with plant Mo uptake (Karimian and Cox 1979). However, it does not accurately reflect the availability of soil-Mo over a wide range of soil properties (Reisenauer et al. 1973). Very limited growth chamber work showed the resin test to have some utility in Saskatchewan soils after sodium molybdate fertilization (Stewart et al. 1979), but Mo tests are in general unproven locally. A hot water extraction (Lowe and Massey 1965) would be convenient if the same extract could be used in the B test, but procedures as originally proposed are not identical. Again, there is the problem of verifying a nutrient availability test when no local soils known to be deficient are available.

Plant analysis methods vary somewhat among laboratories (e.g. wet vs. dry ashing for certain elements) (Table 1). Since total amounts of elements are determined, one might expect good agreement among laboratories and methods. However, great care must be exercised; there was considerable variation in results from several American laboratories which analyzed identical plant samples for total nutrient element concentrations (Watson 1981). Micronutrients generally showed highest relative variations with B and Fe being particular problems. Molybdenum was not determined in the latter study.

Sample exchanges and routine use of plant material standards should point out problems in plant analysis techniques. Effective use of results require an accuracy of about ±10-15%. Verifying the accuracy of individual methods should be more important than standardization of methods among labs, though the latter would also be not difficult to achieve. Effectiveness of the digestion methods is often implicated in variability of results.

Exchange of digests and extracts among labs may point out analytical technique problems. Use of inductively coupled plasma spectroscopy is becoming popular, while atomic absorption and colorimetric determinations are also in use (Table 1).

Hamilton (1980a, b) discussed soil trace element analysis at length, including quality control and sources of contamination. Plant and soil sampling is often carried out by people unaware of proper procedures and sources of contamination, so recommended sampling and packaging procedures should be made available. In Western Canada most soil testing laboratories were set up primarily for, and still work mostly with, macronutrient analysis. Thus the existing equipment, methods, and environment may be inadequate, and personnel not properly trained, to prevent contamination or do accurate analyses in the sub-ppm range.

Delineation of areas or soils with micronutrient deficiencies initially requires extensive crop survey information, along the lines of studies reported by Stewart (1969) and Sadler and Fehr (1975). Known relationships between extractable or plant-available micronutrients and soil properties, together with existing regular soil survey information, could suggest possible problem soils for more intensive sampling. Results of micronutrient tests run to date on farm samples should also serve as a guide in site selection. Extensive surveys would consist of paired plant and soil samplings and analyses. Yield trials at sites of suspected problems would then be needed to verify soil testing methods and determine critical levels for local crops and soils. Many such sites could be used since full scale test plots would not be necessary. Strip applications of micronutrients in farm fields prior to seeding, and paired yield sampling, would be adequate to detect responses. Unless sites are found on which yields respond to micronutrient fertilization it is difficult to fairly judge the merits of soil test methods or place much confidence in critical levels being quoted for plants and soils, especially the latter.

The usefulness of plant analysis, especially in the initial stages of a survey and before soil test methods are verified locally, cannot be overemphasized. Several reviews of plant analysis are available (Walsh and Beaton, eds. 1973, Dinauer, ed. 1967, Jones 1972). A plant tissue analysis guide, including sampling details, is published in Manitoba (K. McGill, Plant Tissue Analysis, Manitoba Agriculture Farm Facts, Agdex 533, March 1981). The B.C. Ministry of Agriculture outlines leaf sampling in orchards in its Tree Fruit Production Guide for Interior Districts, 1981, and also distributes a leaflet entitled "Leaf Analysis for Greenhouse Vegetable Crops" (1977). At present, critical levels used in interpretation of plant analyses are probably more dependable than those used for soil analysis. Plant critical levels too are in need of local verification, a task on which some work has been done in Manitoba.

6. Conclusions and Recommendations

Soil and plant analyses for micronutrient deficiencies are, with a few exceptions, relatively new and untested procedures in Western Canada. The tests, interpretive criteria, and analytical methods are mostly still in need of verification locally, and the micronutrient status of our soils is known only in the very broadest of senses. In this light, the following are suggested for consideration:

1) Standardization of micronutrient test procedures across Western Canadian laboratories. Procedures must be precisely identical, particularly for the DTPA test, if research results are to have general applicability.

2) Review of conditions, instrumentation, and personnel training in individual laboratories where micronutrient work is done, in consideration of the special requirements for these analyses (accuracy, prevention of contamination); sample exchanges and use of "standard" soils and plants to maintain accuracy.

3) Correlate results of presently used tests to those from the combined micro- and macronutrient test employing the extractant NH_4HCO_3 + DTPA (Soltanpour and Schwab 1977). Routine use of

this extract for farm samples could give much information about the micronutrient status of soils at minimum cost, particularly if coupled with ICPS techniques.

4) Use of present information, soil survey in particular, to predict soils with potential deficiencies, followed by extensive paired plant/soil sampling and analysis, and use of simple fertilizer response trials on an even more selective basis. Yield trials are essential to derive valid local test criteria.

5) Surveys should be carried out of farmers who have used micronutrients.

6) Testing of the relative merits of 0-15 cm vs. deeper sampling for micronutrient soil tests, especially for the anions (B and Mo) which move more freely than micronutrient cations in soil.

7) Emphasis of the need for ongoing field surveys and research (at least four years) due to the high degree of year to year variability in available micronutrient levels and crop responses to them.

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