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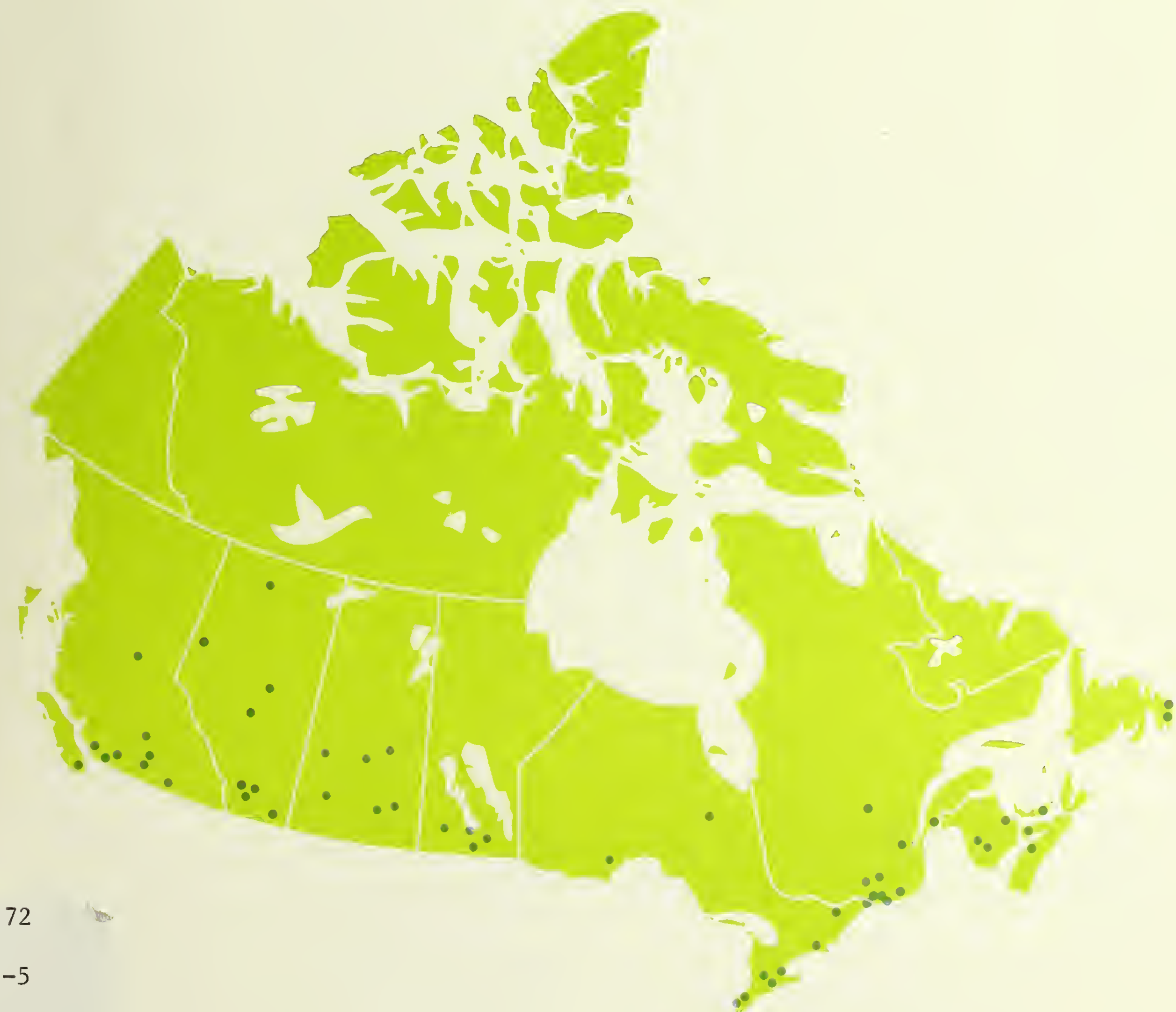

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The dots on the map represent Agriculture Canada research establishments.

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Assessment of the need for micronutrient applications for agricultural crop production in British Columbia

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CONTENTS

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PREFACE

Questions about the need for applying micronutrients for crop production in British Columbia are continuously being raised. There are many and diverse opinions, but the basis for these are often unclear i.e. are these based on local research data, general observations or extrapolation from literature reports of studies conducted in other areas? This report was initiated as a project of the former soil fertility workgroup of a subcommittee (soil management) of the British Columbia Land Resource Science Lead Committee to provide documentation of local research data on micronutrients. This information should provide a basis for refining current practices and determining research priorities.

SUMMARY

A number of micronutrients (boron, copper, zinc, manganese and iron) have been used for crop production in British Columbia for a number of years as a result of research on micronutrients conducted as much as 50 to 60 years ago. The research on these and other (aluminum, molybdenum, chlorine, cobalt, selenium) microelements under actual British Columbia conditions have shown varying responses to applications. Responses have been changes in dry matter production or concentrations of the element in plant tissue. However, the research conducted has not been thorough nor has there been a sustained program on any of the elements. Micronutrient fertilizer applications have been largely confined to areas of the province (south coast, Okanagan and Similkameen Valleys and Kootenay area) where crops are grown under intensive management. Soil testing is used extensively for determining boron deficient areas but soil tests for the other micronutrients have not been satisfactorily researched locally. Leaf tissue testing is used in some instances. Micronutrient toxicities have been documented in a few cases. Micronutrients are also a concern in the forage-based animal production areas of the interior but tend to be related to livestock feed quality rather than to crop growth requirements. More research data is required to fully identify the distribution and significance of micronutrient problems in the province. This should be followed up by research on methods for ameliorating the problems, whether deficiency or toxicity.

RÉSUMÉ

On a utilisé pendant quelques années un certain nombre d'oligo-éléments (bore, cuivre, zinc, manganèse et fer) en production végétale en Colombie-Britannique, à la suite des recherches effectuées il y a 50 à 60 ans dans ce domaine. L'application de ces oligo-éléments et d'autres (aluminium, molybdène, chlore, cobalt, sélénium) dans les conditions de croissance dans cette province a produit divers effets, soit des modifications dans la production de matière sèche ou dans la concentration des oligo-éléments dans les tissus végétaux. Cependant, les recherches effectuées n'ont pas été exhaustives et aucun programme soutenu qui évaluerait la nécessité de ces oligo-éléments n'a été mis en oeuvre. En effet, les applications d'oligo-éléments sous forme d'engrais ont été à toutes fins utiles restreintes à certaines régions de la province (sud de la côte, vallées de l'Okanagan et de Similkameen, et région de Kootenay) où les cultures font l'objet d'une gestion intensive. L'analyse du sol est couramment utilisée pour déterminer les carences de bore, mais pour ce qui est des autres oligo-éléments, elle n'a pas fait l'objet de recherches satisfaisantes dans les conditions locales de croissance. On utilise parfois l'analyse des tissus foliaires à cette fin. On a ainsi pu signaler certains cas de toxicité aux oligo-éléments. Ceux-ci posent également un problème dans les régions de l'intérieur où l'élevage repose sur la production fourragère, mais ils sont reliés à la qualité des aliments du bétail plutôt qu'aux besoins de croissance de la culture. Il faut donc intensifier les recherches pour pouvoir établir la répartition et l'importance des problèmes liés aux oligo-éléments dans la province, et les faire suivre de travaux sur les méthodes destinées à atténuer les problèmes de carence ou de toxicité.

INTRODUCTION

Agricultural production in British Columbia occurs in a relatively small proportion (2 to 3%) of the province with the activities restricted to valleys and plateaus in the generally mountainous terrain (Kowalenko 1987). Although the land area used for agriculture is small, the value of production is relatively high and is an important industry in the province. Agriculture is quite diverse, ranging from the production of various types of livestock (dairy, beef, swine, poultry layers, poultry broilers, etc.) and crops (forages, cereals, vegetables, small fruits, trees fruits, etc.). The intensity of production varies throughout the province and depends on climatic, soil and market conditions. A wide range of fertilizers are used by growers because of the diverse, regional and relatively intense type of production. There has been an increased but variable use of a number of micronutrients since 1984 (Table 1) as shown by retail sales records (McLean,

Table 1 Quantities of micronutrient fertilizers retailed in British Columbia for years ending June 1[1]

Nutrient	1984	1985	1987	1988	1989	1990	1991
	metric tonnes						
Boron	23	23	42	112	70	104	131
Copper	10	10	8	24	26	32	23
Zinc	20	20	26	44	68	97	54
Manganese	2	2	3	17	27	28	16
Iron	27	150	78	272	228	179	233

[1]Available figures show no micronutrient sales in the Peace River area of British Columbia except for 25 mt of zinc in 1990.

personal communication). It should be noted that although information from fertilizer sales provides a fairly useful picture of the trend in micronutrient use, the data should be used with caution. For example, iron has been included in blends for lawn fertilization usually as a moss inhibitor rather than as a nutrient.

Although it is generally assumed that micronutrients are required for optimum crop production in the province, the precise basis for this assumption has often not been thoroughly nor critically evaluated. There have been several reviews related to micronutrients for British Columbia, but they are either quite old (Stokvis 1939, Tamura 1941, Hill 1949) or of relatively limited scope, thoroughness or availability (John 1971, Warren et al 1971, Kowalenko 1985). In 1980, boron was the only micronutrient soil test that was included for interpretation by the provincial testing laboratory (Neufeld 1980). Other micronutrient analyses were included several years later (Yee and Broersma 1988) largely due to the questions from and interest by growers rather than as a consequence of local research.

In order to evaluate the need for micronutrients, this publication will thoroughly review research on nine plant and/or animal micronutrients (boron, copper, zinc, manganese, iron, molybdenum, chlorine, cobalt, and selenium) and a closely related microelement (aluminum) potentially important for crop-based agriculture in British Columbia. Because of the diversity of agriculture and current micronutrient use in the province, the elements will be reviewed within the context of four crop and climate combinations related, but not confined, to distinct geographic areas. The areas will be similar to that used for a nitrogen review (Kowalenko 1987): south coast, Peace River, interior areas under extensive management (mainly forage crops) and interior areas under intensive management (mainly horticulture crops). The south coastal area is relatively humid and has a moderate yearly temperature with intensive crop production. The main crops are vegetables, small fruits and forages. Peace River agriculture is mainly centred around cereals and forages. Large areas of the interior are used for cattle production with extensive rather than intensive use of the land base. Also within the interior, horticultural crops under intensive management are grown in specific areas such as the Okanagan, Similkameen and Creston Valleys. Tree fruits and grapes are the main, but not only, horticultural crops.

BORON

SOUTH COAST

Research on boron was initiated in south coastal British Columbia when a serious problem with decline of raspberry plants was studied (Harris 1940) and it was found that micronutrient application including "boron ... at 25 lb./acre" on raspberry plants with mosaic disease resulted in increased yield. Atkinson and Wright (1942) observed that boron measured in boiling water extracts of soil was the only factor measured that appeared to be related to visual differences in growth of raspberries. They observed that "all poor areas showed less than 0.20 ppm B and all good areas showed 0.25 ppm or more, while that marked excellent ... showed the highest value (0.37 ppm B)". Harris (1944) subsequently recorded an increase in percentage dry weight of raspberries not only to boron but also to manganese and zinc application. At about the same time White (1940), using a sand and water culture to examine the response of tomato and wheat to boron, found increased growth when nutrient solution boron was less than 5 ppm but decreased growth at 5 ppm. Tamura (1941) concluded that a University of British Columbia soil growing red clover may become deficient in boron if the soil was heavily limed, and that liming may be required to reduce boron toxicity of a Lulu Island soil. Boron extracted from the soil using Spurway's method using acetic acid was explored in this study. Gregory (1947) noted that a deficiency of boron could decrease the incidence of clover nodulation. Carrot and turnip yields and keeping quality were affected by boron in certain cases in a field trial on three different soils of the coast including a peat plus two mineral (identified as "Milner" and "Aldergrove") soils (Harris 1943). Carrot yield tended to increase but turnip yield tended to decrease. Storage quality of both crops tended to increase with boron treatment. A general micronutrient study by Larson (1949), which included boron, was inconclusive because of Late Blight disease in tomato used as the test crop. Wiens (1949) found that radishes were very sensitive to boron toxicity. Wright (1951) found that certain soils of the Fraser Valley were boron deficient for lettuce production and that a chemical test, rather than a biological test using sunflower, was potentially better at indicating low soil boron. Whitehead (1951) also found that strawberries could be detrimentally affected by excessive amounts of applied boron. Magel (1951) included boron as a micronutrient treatment on cucumbers in a pumice based study but the high ash (or mineral matter) content of the growing medium was concluded to have compromised the results by limiting plant growth. Phillips (1952) found that boron, as well as molybdenum, increased seed yield of red clover on a sandy loam soil, while Kynaston (1953) found that micronutrients including boron influenced the germination of various forage plants. Gold (1959) described boron deficiency symptoms of strawberry plant in a solution culture system. Although a number of the early plant-oriented studies mentioned above were not entirely successful nor definitive, they did show that there was a continuing concern for the potential for boron deficiency in south coastal British Columbia.

Early examinations of the boron content (total and "available") of British Columbia soils suggested that those in the south coast varied from adequate to deficient (Fennell 1947, Heal 1948, Henley 1950, Fennell and Laird 1953, Day, Farstad and Laird 1959). These studies showed that generally soils with great amounts of clay or organic matter tended to have greater boron contents but exceptions were noted. Also, liming tended to reduce boron availability.

After a dearth of reports on boron research in the 1960s, research on boron appears to have been initiated once again in the late 1960s and early 1970s. Beaton, Speer and Harapiak (1968) incidentally included boron in a study on the liming potential of an electric furnace slag (0.05% boron) but the role of boron was not specifically evaluated. John, Carne and Eaton (1971) concluded that there was a possibility of widespread boron deficiency in Fraser Valley raspberries. This conclusion was based on a leaf tissue survey. Subsequent research focused on various factors (such as plant genotype, date of sampling, age of plant, etc.) that would influence the interpretation of leaf analyses (John and Daubeny 1972, John, Daubeny and Chuah 1976). Although these studies suggested that leaf analyses may show some promise for boron recommendation purposes, Kowalenko (1981b) concluded that leaf boron concentrations are not consistent enough from year to year for this purpose. The field site related to the leaf tissue analyses study was found to be deficient in boron since there was a berry yield increase of 23% over the three years when 1 kg/ha of boron was applied to the soil (Kowalenko 1981a). Although soil analyses of the site showed relatively low (0.13 to 0.20 ppm B) hot water extractable boron, the tendency of growers to band fertilizers next to the row would complicate obtaining a representative soil sample. About the same time that raspberry nutrient requirements of Fraser Valley soils were being researched, some work was initiated on strawberries. These studies, however, were related to factors affecting leaf tissue concentrations (John, Daubeny and McElroy 1975, John et al 1976), or examining the basics of boron nutrition using solution culture (Neilson and Eaton 1983). Leaf tissue sampling for determining the boron status of filberts was also found to be of limited usefulness, largely because of the variability of boron concentration over time (Kowalenko and Maas 1982b, Kowalenko 1984c, 1984d, 1984e). A field study, where boron was a treatment, did not detect a growth or yield response of filbert (Kowalenko and Maas 1982a). Applied boron appeared to have been taken up by the plant since leaf boron concentrations were increased. This shows that leaf boron analyses may be useful in research studies for comparing treatment effects at a given location but are of limited value for diagnostic purposes. Boron deficiency has been identified in forest trees in the south coast and research has concentrated on leaf tissue analyses as a potential diagnostic technique (Carter, Otchere-Boateng and Klinka 1984, 1986; Davis 1987). Most of the deficient trees had leaf boron concentrations below the 8-12 ppm reported in the literature as being sufficient for similar trees.

The potential for boron deficiency was apparently suspected by John, Case and Van Laerhoven (1972) in a liming study of Fraser Valley soils since boron fertilizer was added to eliminate the possibility in a pot trial. In contrast, Maas (1975) did not observe a response by sunflower to boron (included together with other micronutrients) when the general nutrient status of organic soils was evaluated in pot studies. John, Chuah and Van Laerhoven (1977) found that there was a relatively good relationship between plant (spinach and corn) tissue boron and hot water soil extractable boron, but soil properties such as specific surface area, organic matter content, and extractable aluminum and iron influenced the relationship. It was postulated that the reason these soil properties influenced the relationship was their enhancement of boron adsorption. By 1980, the hot water extraction for boron was accepted as a useful method for determining boron fertilizer requirements (Neufeld 1980). A hot water extractable boron value of 0.20 ppm B was assumed to be very low and fertilizer recommendations were varied for different crops according to their perceived requirements. Four categories of crops were used depending on whether they were sensitive to boron or had low, medium or high requirements. Grasses were classed as low requiring and that may be why Kowalenko (1984b) did not observe a response to boron application on orchardgrass despite large responses to sulphur and nitrogen combinations. Boron was apparently assumed to be a sufficiently important nutrient for soils of the Fraser Valley since some analyses were included in local soil surveys (Luttmerding 1981). Unfortunately the method of analysis was not stated. Recently, Kowalenko (1991) found that hot water extractable boron in the surface 15 cm of soil decreased consistently from fall to spring in six fields on Monroe soil in a study over three winters. Subsurface (15-60 cm) soil analyses did not detect leaching and it was therefore concluded that the over-winter decrease was either due to leaching beyond the 60 cm depth or a change in the extractability of boron. The two corn fields included in the study tended to have higher fall-sampled extractable boron than the four grass fields. Inorganic fertilizer was applied on the grass, whereas manure (cattle and/or poultry) was applied on the corn. Bomke and Lowe (1991) detected an average of 19 ppm boron in manure from a deep-pit poultry barn but application of this manure at up to 40 t/ha to soils in a pot study resulted in little change in forage crop boron concentrations. The forage crop consisted of an orchardgrass-ladino clover combination and the ladino clover boron concentration (23 ppm) was considerably higher than that in the orchardgrass (5 ppm). The influence of various other elements on boron in plants grown in hydroponic systems have been conducted (John 1976, Kowalenko 1989), but these provide basic knowledge of factors affecting boron nutrition rather than an assessment of the status of boron in the soil.

Chae and Lowe (1976) included boron in a literature review of the trace element content of parent materials of British Columbia but the data available was quite limited, therefore conclusions about the general boron status were quite tenuous. In a study of the potential for sodium hypobromite digestion to provide a method for determining total boron in soils (Kowalenko 1979), it was observed that several different methods did not agree on the amounts determined. The amounts varied among the soils (all from the south coast) used. It appeared that the percentage of silt and the amount of organic matter in the soils influenced the total boron determined by the various methods. Recovery of added boron from Monroe soil was incomplete by the digestion methods, suggesting that fixation of boron may also be an important soil factor to consider. Gu (1986; Gu and Lowe 1990) studied the adsorption of boron by various soil organic constituents, which provided a better understanding of boron reaction in soils. These studies show that additional research is required to provide a better understanding of boron reserves in various south coastal soils.

Several studies have been oriented toward the methods used for analysis which provide local information from which other studies can be more effectively accomplished. John, Chuah and Neufeld (1975) examined the use of azomethine-H, whereas Kowalenko and Lavkulich (1976) and Kowalenko (1979) examined a modified curcumin method for soil and plant analyses. Both methods appear suitable for a range of analyses. John (1973) developed a batch-handling technique for hot water extraction of boron from soils. An acid extraction was proposed for a rapid method for boron analysis of plant materials (John 1975). The method appeared to show promise, but it was not fully tested under field conditions.

Although boron deficiency in the south coast of British Columbia has been documented over the last fifty years, the research has been relatively fragmented by studies being scattered over time and on a wide variety of crops. Considerable work has been conducted on plant tissue, particularly for perennial crops, but the variability of leaf boron concentration appears to be too great for diagnostic and recommendation purposes. Soil testing appears to be the most viable method for predicting boron fertilizer recommendations, but local field data to support its use is quite limited. There is a dearth of documented local research on optimum methods of applying boron fertilizer and methods recommended are probably adapted from research in other areas.

INTERIOR - HORTICULTURE

Boron deficiency was detected in the Okanagan more than fifty years ago when it was found that boron application directly into the trunk of the tree, sprayed on the leaves or applied on the soil eliminated drought spot and corky core of apple (McLarty 1936, McLarty, Wilcox and Woodbridge 1936, Wilcox 1938). There was also early recognition of sensitivity of fruit quality to excess boron. Storage quality of fruit was shown to decrease when fertilizer boron resulted in fruit boron concentrations greater than 24 ppm dry weight (Wilcox and Woodbridge 1943). Plant and soil analyses were examined as methods for diagnosing boron deficiency and it appeared that twig analysis was more successful than soil analysis for prediction purposes (Woodbridge 1937). The application of boron was quickly implemented by growers and substantial increases in marketable fruit resulted (McLarty 1940). Research also showed that boron deficiency occurred on apricot (Fitzpatrick and Woodbridge 1941), pear (Woodbridge, Carney and McLarty 1951) and peach (McLarty and Woodbridge 1950). Boron deficiency was found when the soil moisture content was low in the fall and early spring, despite apparently adequate soil boron concentrations (Woodbridge, Carney and McLarty 1951). A sand culture study, conducted to further define the symptoms of deficiency and toxicity, also examined the relationship between boron content of the plant and the visual symptoms for peach, prune and sweet cherry (Woodbridge 1955). Boron was shown to be relatively well fixed in tree fruit leaves and did not leach from fruit leaves when dipped in detergent washes in a study to determine washing techniques for removing contamination (Ashby 1969a). There was, however, some evidence of boron movement into detached fruit leaves upon being dipped in a boron containing solution. Houlden (1951), who conducted a greenhouse boron deficiency study with Okanagan soils because "... boron deficiency has been known as a deficiency of commercial importance in the Okanagan Valley for many years ...", was not able to detect visual deficiency symptom with radishes as the test crop. These results were considered inconclusive since only visual symptoms were considered and the chemicals used may not have been sufficiently pure. However, Leggatt (1948), who also used radishes as a test crop, showed that boron deficiency occurred in a Creston area soil. It was concluded in a soil survey report that boron deficiency was quite widespread in the Upper Columbia and East Kootenay areas (Kelley and Holland 1961). Boron deficiency was also found to be associated, together with calcium, in the breakdown of Spartan apple fruit during storage (Lidster et al 1975). Increased breakdown of the stored apples was correlated with increased concentrations of boron in the flesh.

By 1980, hot water extractable boron from soil was regularly used as a method for determining boron deficient soils (Neufeld 1980). Tree fruits were considered to have high requirements for boron and boron fertilizer was recommended when soil extractable boron was 0.20 ppm or less. Boron was recommended as a regular soil treatment (B.C. Min. Agric. and Food 1985b) and boron was applied to the soil to ensure adequate nutrients in a study using municipal waste water to irrigate apple trees (Neilsen et al 1989). Municipal wastewater from Osoyoos was shown to contain 0.37 ppm B (Neilsen et al 1989), while from Kelowna, effluent contained 0.78 and sludge contained 1.22 ppm B (John, Chuah and Neufeld 1975). Leaf tissue analysis was recommended for grapes and adequate boron was assumed when bloom time petiole concentration was 25-50 ppm B for labrusca and hybrid types and 30-100 ppm B for vinifera types (B.C. Min. Agric. and Food 1985a).

More recently, tree dieback resulting from boron toxicity was identified in peaches in the Okanagan (Neilsen et al 1985). The study showed that when leaf boron was greater than 130 ppm, boron toxicity always occurred. The incidence of boron toxicity may be a result of excessive or even continuous regular application as a fertilizer and also the increased availability of boron as orchard soils acidify (Tamura 1941, John, Case and Van Laerhoven 1972, Woodbridge 1940). Intensive orchard management has been shown to accelerate soil acidification (Ross, Hoyt and Neilsen 1985). Neilsen et al (1985) suggested that the desirable boron content of peach leaves was 26-50 ppm. Leaf and soil boron were found to be closely related, except when boron was concentrated near the soil surface or when it occurred deep in the profile. More recent commercial recommendations caution against excessive soil boron applications and advocate foliar boron sprays as an effective method of maintaining boron nutrition for peaches, prunes and apricots (B.C. Min. of Agric. and Fisheries 1989). These three orchard crops are known to be especially sensitive to excess boron. Woodbridge (1940) did show evidence that there was some movement down the soil profile, particularly in sandy soils. Hoyt (1988) discounted boron as a factor in internal bark necrosis symptoms in "Delicious" apple after leaf and soil analysis.

Kelley and Spilsbury (1949), from soil analyses conducted by Woodbridge (1940), concluded that "the low boron content of Okanagan soils was perhaps sufficient to serve the needs of the native vegetation, but proved to be inadequate for cropping". Fennell (1947) concluded from soil analyses that Okanagan soils tended to be deficient in available boron, and subsequent work (Fennell and Laird 1953) suggested that available boron decreased when the soils were cultivated. Chae and Lowe (1976) found relatively little total boron data for Okanagan soil parent materials.

It has long been established that the major horticultural crops in the irrigated interior require periodic boron applications to avoid boron deficiency. Many of these soils are low in available boron due to low total boron in parent materials and low organic matter contents of native soils. Excessive application of boron has occasionally been associated with toxicity on sensitive crops or quality reduction such as reduced storage quality of apples. Despite recommendations for applications of boron fertilizer to many of the commercial crops, there have been few studies of soil boron levels or boron leaching. Much more attention has been given to tissue boron concentrations, especially for major tree fruit and grape crops.

INTERIOR - FORAGE

Boron deficiency for the production of forage crops in the interior area of the province has been researched for more than fifty years. McLarty, Wilcox and Woodbridge (1937) provided evidence that yellowing of alfalfa grown on soils in the Okanagan and Kootenay valleys was reduced by applications of boron, and that the yellow plants had a consistently lower concentration of boron in the leaves than normal green plants. Kelley and Spilsbury (1949) speculated that although soil boron content (Woodbridge 1940) was probably sufficient for native vegetation, it was inadequate for cultivated crop production. Farstad and Laird (1954) speculated from soil analyses that Brown Podzolic and Grey Wooded soils of the Quesnel, Nechako, Francois Lake and Bulkley-Terrace areas also tended to be marginal in their available boron supply, while Black soils with a higher organic matter content were adequate. They did note that the available boron in the parent material of Grey Wooded soils were relatively high and may provide sufficient boron for crop growth. Survey and plot trials have indicated that boron deficiency is relatively widespread in the interior (Kline 1981). More recently, in a field study on the Creston Flats, Gough (1985) reported that foliar applications of boron on yellow mustard increased yield and reduced purple interveinal stripes and green-yellow stalks associated with boron deficiency. There was a response to the boron application when the soil test value for boron (hot water extraction) was 0.42 ppm or less.

Although studies have shown boron deficiency in the interior, a number have documented little response to treatments that included boron application. Mason (1964) did not detect a response by alfalfa to boron application near Armstrong on black soils, even though there was a considerable response to other micronutrients. Pringle and Van Ryswyk (1965) did not detect a response by water sedge (Carex aquatalis Wahl.) in a growth room study to multiple trace elements, including boron, which were applied in fritted form on peats from the Williams Lake area. Freyman and Van Ryswyk (1969) did not observe a response by pinegrass to a multiple micronutrient solution (Long Ashton's) application to a Grey Wooded soil. Osoyoos soil apparently had adequate boron for ryegrass production when Ashby (1969b) tested the effectiveness of applying boron, and other nutrients, in an encapsulated form. In fact, there was some evidence that encapsulation reduced boron toxicity. Similarly, Neale (1973) found evidence of mild toxicity to boron from applications on sweet clover in a growth chamber study using Dogtooth sandy loam soil. Miltimore et al (1973) determined boron in a forage-oriented study at two locations both identified as Nisconlith soil (one being sandy loam and the other clay loam) and it appeared, from the lack of comment on the analytical results, that the boron was adequate . Haak (1980) similarly infers that boron was adequate in soils near Afton Mines after little comment on boron analyses of a range of soil and plant samples. Recently Chuah (1990) has observed that around one-half of the samples submitted from the central and northern interior of the province to the soil test laboratory were rated as being low to medium in boron content. The soil test used by the laboratory has been a hot water extraction and the recommendation is modified according to the general requirement of various groups of crop plants (Neufeld 1980).

General soil-oriented studies, such as that on total boron of soils (Fennell 1947, Fennell and Laird 1953) and parent materials (Chae and Lowe 1976) or "available" boron (Henley 1950), showed that the boron content in the interior varied widely. However, these studies are dated and may not be very indicative of the current situation. Thus, the relationship of different crops to boron fertilization should be extrapolated with caution.

Several thesis studies provide some limited basic information on boron in relation to plant growth, largely through "artificial" rooting media (White 1940, Brown 1943, Gregory 1947, Cooke 1949, Kynaston 1953). These studies are quite dated, do not incorporate recent soil-plant boron research and provide negligible information under field conditions. John, Chuah and Neufeld (1975) used an alfalfa sample from interior British Columbia during an assessment of a colorimetric method for determining boron but, since there is little documentation of the sample site, the study primarily provides general information on a laboratory method. A study by Kowalenko (1979) on a digestion method for boron analysis of plant and soil materials included soil samples from the interior of the province, but the information provides only general relationships of total boron in soil by different methods to certain other soil analyses and is not very specific for interior soils. A study by Majid (1984) on lodgepole pine and Douglas fir in interior British Columbia primarily concentrated on the development of a method for determining the nutrient status of trees rather than the examination of the extent of boron deficiency, sufficiency or excess. Although Gu (1986, Gu and Lowe 1990) used a soil sample from near Kamloops in a basic study related to boron adsorption, the information is of limited usefulness and does not provide an assessment of the boron status of the soils of the interior.

There is documentation of boron deficiency in soils of the interior of the province used for forage production. The instances of deficiency are not general and tend to occur in certain locations. This variation appears to be related to the boron content of the soil, although the type of crop also plays a role. Deficiencies were largely found with crops (alfalfa, yellow mustard) that generally require more boron than grasses and cereals. Although soil testing appears to provide an objective basis for determining boron deficient areas, there is little documented local field data supporting the relationship on which this is based.

PEACE RIVER

There has been much less documented research on boron for the Peace River area compared to other parts of the province. It is probable that this has occurred because of early research by Fennell (1947, Fennell and Laird 1953, Farstad et al·1965, Chae and Lowe 1976) which showed that Peace River soils were well supplied with total and available boron. The hot water extraction recommended for soil test purposes (Neufeld 1980) appeared to be accepted as a suitable method to examine site-specific situations for soil boron status in this region. Baxter (1972) specifically used two Peace River soils in a study on sulphur and boron for rape varieties, but no response to boron was measured. The study, however, only used visual assessments, which would not have been very sensitive to boron deficiency. Thesis studies such as those by White (1940), Gregory (1947), Henley (1950) and Kynaston (1953) provide some basic information on boron for crop production but do not provide information on the status of boron in Peace River soils.

SUMMARY

Boron deficiency has been documented in most areas of the province with the exception of the Peace River area. The hot water extraction of soil boron is widely accepted as the best method for defining site-specific areas for annual and forage crops potentially requiring boron fertilizer. Documented local data to support its use is quite limited, therefore the system appears to be based largely on the extrapolation of research from other areas of the world. Leaf tissue sampling has been emphasized in research for deriving diagnostic procedures for tree fruits, small fruits and hazelnuts. In the case of tree fruits in the Okanagan, toxicity from excessive boron applications has been documented with an influence on fruit storage quality as well as yield. Considerably less research has ben done to document the optimum forms, placement, or rate and time of application to deficient crops or soils. An understanding of boron transformations and movement in the soil would help to refine prediction and application methods, however, band applications of fertilizers particularly on perennial tree or bush crops creates a problem for obtaining a representative soil sample and interpretation of the data.

COPPER

SOUTH COAST

Copper was considered a possible nutrient deficiency problem when generally poor performance of raspberry plants was observed more than fifty years ago (Harris 1940). That study did not come to firm conclusions but it was noted that micronutrient applications including copper may increase the resistance of raspberry plants to mosaic disease. A subsequent field study at the University of British Columbia did not detect an effect by copper on raspberry yield nor berry quality (Harris 1944). About the same time, Tamura (1941) found that copper increased the yield of red clover grown on heavily limed Lulu Island soil. It was also concluded that a University of British Columbia soil did not require copper, or several other nutrients, unless they were heavily limed. Harris (1943) measured an increase in yield and size of carrots with copper addition to a Fraser Valley peat soil, and increased carrot root to top ratios or increased storage quality of carrots and turnips to copper addition on Milner and Aldergrove mineral soils. Wiens (1949) detected an increase in the ash weight and nitrogen content, but a decrease in percentage dry weight, of radishes when copper was applied to a "light sandy" soil in a greenhouse study. Larson (1949) was unable to detected an effect from small additions of copper on tomatoes because of a disease problem. Copper was included in a micronutrient study on cucumbers but the results were incomplete because of a problem of high ash content in two of the blocks which "proved to be the factor limiting all results in the experiment" (Magel 1951). Whitehead (1951) reported detrimental growth of strawberries when micronutrient combinations which included copper were applied in excess. Day, Farstad and Laird (1959) assumed from soil analyses that Vancouver Island soils tended to be adequately supplied with copper. This assumption was supported by reference to some studies at Saanichton Experimental Farm on Dashwood gravelly sandy loam soil where there were no responses by various crops (bulbs, pears) to copper applications. Maas (1975) found that sunflower grown in a growth chamber in Vancouver Island organic soils did not respond to a micronutrient application. The micronutrient treatment probably included copper but the method used was not completely documented. John and Van Laerhoven (1976) must have suspected a potential for copper deficiency since they added copper to a sludge study on Monroe soil "to ensure adequate fertility". Yole (1980) postulated that the poor growth of mustard-spinach when a sludge was applied to a sandy loam soil at pH 5.3 in the greenhouse was due to "excessive salts or increased availability of Cu, Fe, or Mn". Kowalenko (1984c) found that of 17 filbert orchards surveyed in the Chilliwack area from 1978 through 1980, many had leaf copper concentrations less than the concentration (8.8 ppm) which appeared to be optimum for growth using regression relationships with other nutrients. The number of orchards below that concentration varied from one to sixteen during the three years of the study despite no copper fertilizer being applied. This suggested that the orchards had marginal copper concentrations and that copper concentrations varied with environmental conditions. A target leaf copper concentration of 9 ppm has been proposed for filberts (Kowalenko 1984e). Washing the leaves to reduce errors due to copper contamination was shown to be important (Kowalenko 1984d). Bomke and Lowe (1991) found that deep-pit poultry manure, which contained 19 ppm copper, applied at rates increasing from 0 to 40 t/ha to a

Chilliwack area soil (sicl) resulted in an increase in the copper concentration for a forage (orchardgrass-ladino clover) even when the manure application increased dry matter yield. This suggests that the copper applied in the manure was readily available to the crop and/or that the manure increased the availability of copper in the soil.

Copper was included as one of many nutrients studied in raspberries and strawberries of the Fraser Valley (Gold 1959, John, Carne and Eaton 1971, John and Daubeny 1972, John, Daubeny and McElroy 1975, John et al 1976, John, Daubeny and Chuah 1976). These studies provided some useful preliminary information with reference to sampling methods for nutrients in general, but did not get to the stage of actually determining the copper status of plantings in the Valley. Therefore, the copper status of soils used for small fruit production is still unknown.

The copper status of forest trees in the south coast has received some attention (Carter, Otchere-Boatang and Klinka 1984, Carter, Scagel and Klinka 1986, Davis 1987). However, leaf analyses did not detect any obvious copper deficiency problems at the site investigated.

Examination of animal feeds from throughout British Columbia has shown that, although copper concentrations vary considerably and are frequently low, the south coast did not stand out as a particular problem area for this nutrient (Miltimore, Mason and Ashby 1970, Miltimore and Mason 1971). A study of dairy feeds specifically for the Fraser Valley found that a high ratio of copper to molybdenum was associated with instances of unsatisfactory herd performance (Peterson and Waldern 1977). Czerwinski (1979) found that copper application could influence the yield and copper content of timothy and sweet clover plants, whereas molybdenum only increased the molybdenum content. The concentration of copper has been shown to be frequently higher in legumes than in grasses (Bomke and Lowe 1985, 1991). Another survey of dairy feeds in the Fraser Valley found copper values that were somewhat higher than those reported previously but no specific problems with copper were discussed (Cathcart, Shelford and Peterson 1980). Several reports on the copper concentration of animal feeds indicated that those on the coast tend to be similar to provincial averages (B.C. Min. of Agric. 1978, Soder 1984, Anonymous 1984b, Anonymous 1984f). Values, however, ranged considerably suggesting that copper was not a general concern, although specific problem cases may occur.

Clark (1950) compared the total copper content of 38 surface and subsurface samples from uncultivated soils throughout the province. The copper contents, which ranged from 12 to 98 ppm, varied considerably within each region of the province such that no overall trends could be distinguished. Examination of profile samples led to the conclusion that "poorer drainage position in the coastal soils favoured a greater retention of copper in the solum" than observed for other region soils. An acid (0.1 N HCl) extraction was applied only on the samples from the Fraser Valley, therefore, the amount determined (0.65 to 2.72 ppm) could not be compared with soils from other regions. Since no relationship was determined between total and extractable soil copper, the availability of total copper to plants cannot be derived. Since the samples used in Clark's study were uncultivated, the values were only useful as comparisons of the inherent copper content of virgin British Columbia soils. Griffiths (1951) initiated a correlation study between soil extractable and plant copper but, since the plant analyses were not done, the relationship was not determined. Wiens (1968) showed that the availability of copper to ryegrass, pea and lettuce was increased by steam sterilization of the soil, while Maurer and John (1971) found an increased copper content in carrot roots when the soil in which they were grown was fumigated. Chae and Lowe (1976), who focused on parent materials, provide little additional data for total copper in coastal soils than already mentioned and the values shown are more of geologic than crop production interest. McKeague, Desjardin and Wolynetz (1979; McKeague and Wolynetz 1980) report total copper ranging from 23 to 78 ppm in soil profiles from Vancouver Island and the Fraser Valley but, with only seven sites reported, conclusions on their comparative values are limited. Kenney (1983) reported that the Ap of Crescent soil from Westham Island had a total copper content of 37 ppm. Two soils, Marble Hill and Abbotsford, used for raspberry production were found to contain from 14 to 24 ppm total copper and, although a decease in copper concentration was detected down the profile, differences were not detected in fields that had varying manure or fertilizer histories (Wolterson 1989). Yole (1980) found that DTPA soil extractable copper increased considerably with the application of sewage sludges. Yee and Broersma (1988) found that DTPA-TEA, Mehlich III (a combination of acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and EDTA) and acetic acid-DTPA extractions of copper gave comparable and reasonable regressions with plant copper concentrations. Cross (1975) found that copper could complex with soil organic components, which supports the utility of a chelating agent for extracting available copper (Yee and Broersma 1988) and the observation that large applications of poultry manure increase the uptake and leaching of copper (Safo 1978). Wolterson (1989) could not detect differences in Mehlich extractable copper in soils of raspberry fields that had different histories of manure or fertilizer applications. Luttmerding (1981) included limited copper analyses values of representative soil profiles in the survey report of the Fraser Valley. The actual method used for the copper analysis in this report was not well defined. Schreier (1987) reported total copper analyses for Sumas River sediment materials which have some implications for soil productivity in that area. Kowalenko (1991) found that soil copper extracted by a chelating reagent (DTPA plus TEA plus $CaCl_2$ at pH 7.3) did not change from fall to the next spring over three different winters in six fields on Monroe soil at Agassiz Research Station. The extractable copper in the fields differed from year to year and did not respond consistently to the production of grass vs corn.

In a number of studies, copper was included as a secondary consideration. Kynaston (1953) found that a micronutrient seed treatment had an effect on germination of various forage seed types, but the results were dependent on a wide variety of factors. The specific effect by copper was not evaluated. Some copper analyses were reported in studies related to liming (Beaton, Speer and Harapiak 1968, Eaton and John 1971, John and Van Laerhoven 1972), but there was relatively little discussion on the results. Copper contamination as a result of industrial wastes has been a concern in British Columbia (Warren et al 1971, Warren 1975) and has been considered in relation to various elements such as lead (John and Van Laerhoven 1972), cadmium (John

1976), boron (John, Chuah and Van Laerhoven 1977) and manganese (Freeman 1981, Kowalenko 1989). Kenney (1983) found that earthworms were able to regulate the amount of copper in their body tissue when sewage sludge was applied to soils. Although these studies contribute local data, it is difficult to integrate and interpret the information without further work.

The research data available for determining the copper status of south coastal soils is quite limited and most is relatively indirect. A few old studies showed some crop yield and quality increases to copper application, but a number of others did not observe a response. Plant analyses such as for hazelnuts and forages suggest that the copper available in soils for crop production varies from possibly deficient to adequate amounts. Soil analyses also suggest that the copper content of soils varies considerably, but the relationship of these copper analyses to crop growth has not been defined specifically for soils of south coastal British Columbia. Additional research, particularly of yield responses to copper application and correlation of soil copper extraction to crop response, is required to determine the need for copper fertilization for this area.

INTERIOR - HORTICULTURE

Relatively little research directly related to the assessment of the copper status of interior soils for horticultural crop production has been published. McLarty (1936) did not detect a response to copper injected directly into the tree during a study of drought spot and corky core problems of apples grown in the Okanagan. Warren et al (1971) were more concerned with the broad issue of industrial pollution in the province and did not identify any significant copper toxicity problems for horticultural situations in the interior in their survey report. Van Netten and Morley (1983) did observe bioaccumulation of copper by radish grown in soil samples from the Summerland area that were naturally enriched in uranium and contained 40-52 ppm total copper. All the other plant related studies that included copper data were largely studies that examined management factors other than direct copper applications. These studies included fruit removal (Jentsch and Eaton 1982), calcium in relation to breakdown problems of stored apples (Mason and McDougald 1974), orchard floor management (Neilsen and Hogue 1985), temperature (Hogue and Neilsen 1986), strains of "Delicious apple (Jonker 1986), zinc (Neilsen 1988) and irrigation with municipal waste water (Neilsen et al 1989, Neilsen et al 1989). Although this data provides potentially useful basic information on factors likely to affect plant copper accumulation, it does not give conclusive information about the sufficiency or insufficiency of the copper supplying potential of interior soils for intensive horticultural production. It would appear that soil copper was generally assumed to have been adequate. Recently however, several apple orchards have been found to contain mid-terminal leaf copper concentrations less than 4 ppm, which is assumed to show deficient conditions (Neilsen, G.H. unpublished data). Since significant reductions in apple leaf copper concentrations have been observed as a consequence of planting-time phosphorus application in old orchard soils (Beulah 1991), there is potential for induced deficiency problems. At present, the need for copper fertilization is being assessed, but the sensitivity of tree fruits to copper toxicity is also being kept in mind.

Similarly, soil related research that has been done in this region has not derived sufficient information for making definitive conclusions on the copper status of soils. The study by Clark (1950) provides some comparative data for the province but it was concluded that the variation within regions was as great as that between regions. Also, the data is limited for assessing the copper status of soils since only 38 soils were sampled for the entire province. Soils selected were uncultivated and analyses essentially limited to total copper. No relationships to crop production were derived. In most cases where relationships between soil analysis and plant growth were attempted (Griffiths 1951, Yee and Broersma 1988), it is difficult to extrapolate from annual crops used in the studies to tree crops that are the predominant crops grown. This means that various results that are reported for interior soils for horticultural areas (Kelley and Holland 1961, Warren 1975, Chae and Lowe 1976) are also of limited usefulness for assessing the potential need for copper fertilization.

In summary, there has only been sporadic research on soil and crop copper in the irrigated horticultural regions of interior British Columbia. There have been recent indications of low plant copper concentrations in some apple orchards, but the lack of systematic knowledge of available or even total soil copper values preclude an assessment of the seriousness of the problem.

INTERIOR - FORAGE

Probably the first research on the copper status of soils for crop production for the extensively used land of the interior was the soil analysis study by Clark (1950). That study was largely confined to total copper analysis in soils from throughout the province. The few samples analyzed, the large range of copper found in soils both within and between regions, and the unknown relationship between total copper and crop growth limited the possibility of establishing the status of copper supply in this area. Clark did explore the utility of 0.1 N hydrochloric acid extraction for determining available copper but only for coastal soils. Griffiths' (1951) follow-up study on the acid extraction was not able to incorporate plant copper analyses. Farstad and Laird (1954) concluded from an examination of total copper analyses of three soils of the Quesnel, Nechako, Francois Lake and Bulkley-Terrace area that copper was adequate for most crops, but they recognized that they did not have established minimum values for comparison. Total copper in the surface of the three soils ranged from 12 to 35 ppm and the subsurface ranged from 14 to 47. Bhoojedhur (1975) included copper in a general study of adsorption and partitioning of metals in soil and sediment materials from the Salmon River watershed north of Prince George. Warren (1975) and Chae and Lowe (1976) reviewed available total copper analyses of soil samples, but found that the amount of data was quite variable and limited. Ruckle (1977) attempted to determine the relationship between vegetation and various soil nutrients including total copper in a wet meadow in the Shuswap Lake area, but concluded that they did not generally correlate. Lowe and Bomke (1982) found that DTPA extraction looked promising as a method for determining available copper but were unable to define benchmark values with the limited number of samples included in the study. Lowe and Milne (1979), Bomke and Lowe (1985) and Yee and Broersma (1988) tested various extractants, particularly those containing chelates such as DTPA, for determining available copper. However, the data was limited and there is the concern about quality as well as quantity of plant growth used for forage. Chuah (1990) did not identify copper as a widespread micronutrient problem after observation of soil test analyses conducted on submitted samples. Soil survey reports, more recent than that of Farstad and Laird (1954), of interior areas have occasionally reported copper analyses of representative soil samples (Runka 1972, Cotic, Van Barneveld and Sprout 1974, Lord and MacKintosh 1982, Lord and Green 1986, Dawson 1989) but the method of analysis was not always reported. All of these studies did not include actual crop responses to copper, therefore, the copper supplying capabilities of the soils was not established.

Several crop response studies that included copper applications have been conducted with interior soils. Pringle and Van Ryswyk (1965) did not detect a response by water sedge to copper (and other micronutrients) applied in fritted form on two peats from the Williams Lake area in a growth room study. Similarly, Freyman and Van Ryswyk (1969) did not observe a growth response by pinegrass to copper. The copper was applied with other micronutrients in a Long Ashton's solution. Milne (1979), Lowe and Bomke (1982) and Bomke and Lowe (1985) did not detect a growth response by forage to copper application in greenhouse studies on soils from the Vanderhoof area, despite evidence of copper deficiency problems in livestock in that area. Bomke and Lowe (1985) did document an increase in the copper concentration in forage treated with copper. It was concluded that the soils were supplying sufficient copper for normal crop growth, but insufficient for adequate copper for the plant as an animal feed (Lowe and Bomke 1982). Broersma and Van Ryswyk (1979) concluded, from a comparison of plant analyses with literature reports of critical ranges, that the Fleet soil series near Kamloops had adequate copper for corn growth. Czerwinski (1979) reported an increase in both dry matter production and copper concentration of timothy grass and sweetclover in a greenhouse experiment. Copper deficiency in lodgepole pine and Douglas fir in interior British Columbia has been suggested from a foliar analysis study (Majid 1984).

There has also been early concern about quality of interior crops with respect to livestock nutrition (Miltimore et al 1964). A number of subsequent studies on forage materials from the interior have shown frequent instances of deficient concentrations of copper (Miltimore 1967, Fletcher and Brink 1969, Miltimore, Mason and Ashby 1970, Tingle and Dawley 1972, Miltimore et al 1973, Pringle, Dawley and Miltimore 1973, Miltimore et al 1978). Particular livestock nutrition problems have been associated with forages containing a low Cu/Mo ratio, frequently located on groundwater soils (Miltimore et al 1964, Miltimore and Mason 1971). Van Netten and Morley (1982a) observed that the copper concentration of oat plants grown in soil samples from the Summerland area that were naturally enriched in uranium were not correlated with aluminum and molybdenum concentrations. The roots tended to accumulate more copper than above-ground plant parts. The soil samples contained 26-36 ppm total copper and 1-96 total molybdenum. Reports on the analysis of forage samples submitted for mineral analyses showed that copper varies considerable in the interior (B.C. Min. of Agric. 1978, Anonymous 1984a, 1984c, 1984d, Soder 1984). It would appear that the copper supplying capability of interior soils is frequently low enough to be a forage quality problem, but not low enough to reduce crop yield. On the other hand, there is evidence that there could be cases of excessive copper but these are in isolated locations usually associated with industrial activities such as mining (Warren et al 1971, Natsukoshi 1979, Haak 1980).

Several studies, in which copper was included incidentally, provide some useful but limited information for copper management. Kynaston (1953) showed that micronutrients can have beneficial or deleterious effects on forage seed germination, but the specific effect of copper was not examined. Van Ryswyk, Hubbard and Miltimore (1973) found that fertilization of sedge with nitrogen, phosphorus, potassium and sulphur did not improve the nutritional characteristics of the hay produced, however, the hays from the fertilized and unfertilized treatments were deficient (according to chemical analysis values) in a number of elements including copper. Van Adrichem and Tingle (1975) found that nitrogen application not only increased the yield of meadow foxtail but also the copper content. Bomke and Lowe (1991) found that deep-pit poultry manure, applied at rates up to 40 t/ha containing 19 ppm copper on a clay soil collected from near Prince George, not only increased the yield but also the copper concentration of barley silage in a pot experiment. This suggested that the copper in the manure was readily available to crop growth and/or the manure increased the availability of soil copper. The study did not report soil copper data.

Copper deficiency in the interior of the province has largely been associated with problems in animal nutrition rather than with yield increases in the grass. Several studies have included copper treatments on plants but in most cases yield was not been affected. Little analytical data is available from which to determine copper status, since the numbers of soil analyses relative to the large area involved are small and the relationship of the measurements (total or extractable) to plant growth has not been determined. However, soil and plant analysis shows that the copper available in soils for crop growth varies considerably within the region and specific areas of deficiency (for plant growth or animal mineral nutrition) do occur. Deficient areas appear to occur more frequently in "groundwater" (probably gleysolics and organics of sediment deposits) soils. Given the large area of land on which livestock tend to feed, copper deficiency could probably be more economically treated by supplementation of the feed rather than by fertilizer application to the soil.

PEACE RIVER

The earliest documented research on the copper status of the Peace River soils of British Columbia was a province-wide study of total copper (Clark 1950). That study examined only 38 uncultivated soils from the entire province. The total copper content in various areas, including the Peace River, varied as much within the area as from one area to the other. Clark speculated from the copper distribution in northern podzolic soil profiles that leaching of copper in the Peace River exceeded that in coast soils. Also, since the study did not include extractable copper of Peace River soils, the availability of the total copper determined could not be assessed. Chae and Lowe (1976) did not find any documentation of total copper analyses of

Peace River soils other than that reported by Clark. Griffiths (1951) intended to assess an acid extraction as an index of available copper, but plant copper was not measured. Several studies on the micronutrient sufficiency of animal feeds in British Columbia showed that low copper occurred in the province but the studies were not very specific for the Peace River (Miltimore, Mason and Ashby 1970, Miltimore and Mason 1971). In a study more specifically for the Peace River, Pringle (1971) concluded, from a beef liver and forage survey, that a "subclinical copper deficiency may exist in the area". A subsequent feeding trial with beef animals showed that, although forages grown in the Peace River area have low copper concentrations, the cattle performed relatively well on that feed (Pringle, Dawley and Miltimore 1973). A greenhouse study by Czerwinski (1979) showed that copper can increase the yield and copper concentration of timothy and sweet clover under some circumstances but follow-up work is required to determine the significance of the study to actual Peace River field conditions. Reports on feed analysis submitted to the test laboratory (B.C. Min. of Agric. 1978, Anonymous 1984e, Soder 1984) show that general copper concentrations in Peace River forages are quite similar to the rest of the province but the range of values suggest that there may be specific problem areas. A greenhouse study by Yee and Broersma (1988) provides limited information on the potential for soil analyses to determine copper deficient soils but field confirmation would be required.

In summary, there is research data that shows that the soil copper content of some areas in the Peace River region of British Columbia are too low for optimum production of quality feed for livestock production. Research on the potential for copper fertilization to increase crop production is very limited. There are virtually no reports of randomized, replicated field trials that specifically consider potential copper deficiency of crops. Unless more work is done on crop yield response to copper applications, it is probable that the problem of forage quality can be more economically addressed by direct copper supplementation of livestock rather than by copper fertilization.

SUMMARY

The most important documented information on copper problems in the province are for interior areas, other than the Peace River area, that are used for cattle production. Apparently, feeds produced on soils from this area are often sufficiently low to cause copper deficiency in the animals. Much less is known whether copper fertilization will result in increased crop growth, but it appears that sufficient copper is available for plant growth. If that is the case, then it may be more efficient to supply copper as a supplement directly to the animal than via the plant using fertilizer. Little research has been conducted to determine whether management practices such as fertilization and irrigation, which may be applied to increase the intensity of forage production, will induce copper deficiencies in the crop. Research to determine the copper status of the intensively cultivated areas of the province (south coast and Okanagan) has been much more sporadic and often not specific to copper. A consistent and focused research effort is needed to determine whether copper is potentially a nutrient problem or not. Soil copper research has been much more sporadic, making any application of a soil test to be premature and reliance on the extrapolation of information from other areas of the world is necessitated.

ZINC

SOUTH COAST

In a 1940 report, when it was observed that raspberry plants on a Fraser Valley soil that had received micronutrients were more resistant to mosaic disease, Harris (1940) suggested that more work on micronutrients was warranted. In a later report on raspberries, yield and carbohydrate contents were increased by zinc application in a field study at the University of British Columbia (Harris 1944). In contrast, Tamura (1941) did not observe a response by red clover to micronutrients in a study using a University of British Columbia soil. There was, however, a concern that the different sizes of pots in the study may have compromised the results. Harris (1943) measured an increase in carrot yield and size to zinc application on a peat soil and in turnip yield to zinc on Milner soil. Carrots were tested on three soils (peat and two mineral soils) while turnips were tested only on the two mineral soils. Zinc application was also observed to increase the storage quality of both carrots and turnips. Larson (1949) included zinc as a test nutrient on tomatoes but the results were inconclusive because of a Late Blight disease problem. Wiens (1949) found that zinc increased the nitrogen but decreased the carbohydrate content of radishes grown in the greenhouse using a sandy soil. Whitehead (1951) observed some detrimental effects on strawberries due to excessive micronutrient applications, but it was not possible to identify any specific role of zinc since the micronutrients were not applied individually. Early interest in micronutrients, including zinc, resulted in several thesis studies in the 1950s which considered some basic micronutrient relationships. The studies included cucumbers grown in a non-soil medium (Magel 1951), germination of various forage seeds treated with micronutrients (Kynaston 1953) and micro-element deficiencies of strawberries (Gold 1959). These provided some basic information but little indication of the zinc status of coastal soils.

Vancouver Island organic soils did not appear to be deficient in zinc (Maas 1975), but the pot study with sunflowers was not a thorough test and the results should not be extrapolated without further work. Kowalenko, Maas and Van Laerhoven (1980) reported a probable lime-induced zinc deficiency with oats on Hjorth soil at the Agassiz Research Station. Although zinc uptake by the oats crop decreased as limestone application rate was increased from 0 to 44 t/ha (and soil pH increased from 5.2 to 6.4), extraction of zinc from the soil with neutral normal ammonium acetate did not change accordingly. Soil zinc extraction values ranged from 3.2 to 4.0 ppm. This field trial has been followed up with a study involving zinc (and manganese) application on the same field area and preliminary results confirm that there is a problem with zinc deficiency when lime is applied (Kowalenko 1980a, 1980b, 1983, 1984). However, the responses complex, with crop responses varying from year to year. Both plant and soil analysis will be needed to fully interpret the yield and visual responses observed. Gill (1983) did not observe zinc deficiency in various Fraser Valley soils with pH values as high as 6.5 using broccoli and brussels sprouts, but did observe decreased plant zinc when soil pH was greater than 6.0. It was concluded from the limited available data that practical equations for zinc management were possible through examination of relationships among soil pH, and soil zinc and leaf zinc concentrations.

Although the Okanagan Valley is currently the major area for tree fruit production, there was considerable interest in tree fruits in the south coast in the past. Day, Farstad and Laird (1959) reported that zinc sprays on pear and cherry trees in the Saanich Peninsula did not appear to have been beneficial. A leaf tissue analysis system is recommended for determining the zinc status of filberts (Kowalenko 1984e) with target zinc concentrations set at 20 ppm. These are target values rather than critical concentrations since they were derived from relationships observed in a survey study and extrapolated from literature data (Kowalenko 1984c). The survey study concluded that there was potential for zinc deficiency in commercial Fraser Valley filbert orchards according to the target zinc concentrations. Some related work confirmed the importance of mid-August to mid-September sampling (Kowalenko and Maas 1982b) and showed the need for leaf washing (Kowalenko 1984d) to obtain suitable samples for leaf analysis for zinc fertilizer recommendations. Zinc deficiency of forest stands in the south coast has been tentatively identified from tissue analyses in one forest study (Carter et al 1986) but did not appear to be a problem in two other studies (Carter, Otchere-Boateng and Klinka 1984, Davis 1987). Recently, Gadziola (1991) reported growth and leaf zinc concentration responses to soil and foliar zinc applications on some stands of western hemlock in Maple Ridge and Chilliwack area forests. There was a more immediate response to foliar than to soil applied zinc.

A series of studies have been conducted on the general nutritional status of raspberries, and zinc has been included in these studies (John, Carne and Eaton 1971, John and Daubeny 1972, John, Daubeny and Chuah 1976). The actual status of zinc, and indeed all of the nutrients, cannot be evaluated from the available data since a meaningful sampling system with respect to time, tissue type, etc. was not derived. Some research on other nutrients (Kowalenko 1981b) showed that nutrient concentrations vary considerably within and between years and this variation makes it extremely difficult to interpret tissue concentrations for recommendation purposes. Similar work on strawberries was conducted, but other than examining some of the factors which may influence nutrient concentrations (John, Daubeny and McElroy 1975, 1976), little could be said about the zinc status of south coast soils for strawberry production.

Zinc has been identified as being generally low in animal feeds in British Columbia, where 95% of the sample analyses examined were less than 50 ppm (Miltimore, Mason and Ashby 1970). Surveys of dairy herds and their feeds in the Fraser Valley did not identify zinc as a major problem for reproductive and general performance (Peterson and Waldern 1977). Documentation of forage analyses of the south coast compared with other areas of the province have been made but these values have not been interpreted further (B.C. Min. of Agric. 1978, Anonymous 1984b, 1984f, Soder 1984).

John (1972) conducted an extensive study on zinc availability in British Columbia. Soils from 86 locations throughout the province were included with a number representing the south coast. The study was designed to examine general relationships for a wide range of soils. Corn and oats were used as test crops for availability. Extractions included $CaCl_2$ (0.01 M), $MgCl_2$ (2 N), ammonium acetate (1 N at pH 4.8), chelates (0.005 M DTPA, 0.1 M TEA, 0.01 M $CaCl_2$), North Carolina's acid (0.05 N HCl and 0.025 N H_2SO_4), and Morgan's acidic acetate (7% sodium acetate and 3% acetic acid) and other related soil measurements. The ability of the various solutions to extract available zinc varied for different soil orders. In general, extractable as well as total zinc were greater as soil acidity, clay proportion and organic matter content increased. Multiple correlations showed that soil pH, texture and organic matter content were related to the zinc concentration of the corn and oat test plants. The report provided little documentation of the location where the individual soils were sampled. Furthermore, no dry matter yield effects were shown. A subsequent similar study specifically on Fraser Valley soils, which included the same six extractions of zinc plus extraction with N KCl, showed similar general relationships among corn and oat zinc concentrations and some related soil measurements (John 1974). Zinc extracted by North Carolina acid was the only solution that was not significantly correlated with the zinc concentration of both the corn and oat test crops while the DTPA chelate extraction was significantly correlated with zinc in corn but not in oats. Other soil factors (cation exchange capacity, organic matter content, sand but not clay content and pH in $CaCl_2$ or water) were also significantly related to the zinc concentration of the two crops, either positively or negatively. It thus appears that a range of extractions have potential for determining the available zinc status of soils and that other soil measurements may also improve interpretation. In a liming trial with alfalfa, zinc extracted with N KCl was significantly but negatively correlated ($r = -0.47$) with total top yield (John, Case and Van Laerhoven 1972). The correlation was negative because the liming treatments usually increased crop growth but decreased zinc extractability (Table 2) for all soils studied. It should be noted that the primary concern of the study was to examine the effect of liming on crop growth and that 8.0 ppm zinc was added as a fertilizer to ensure that this nutrient would not limit the beneficial effect of the lime applications. The dramatic reduction in extractable zinc with liming and the correlation of extractable zinc with crop response, despite zinc being applied, probably led John et al (1972) to conclude that "when soils with low amounts of zinc are limed, precautions must be taken to ensure that zinc deficiencies do not result". Kowalenko and Maas (1982a) did not observe yield nor leaf zinc concentration responses by filbert trees to zinc nor lime treatments in field trials in the Chilliwack area. Van Lierop (1987) found that the Kelowna extractant, consisting of 0.25 N acetic acid and 0.015 N ammonium fluoride, to which either 0.005 M DTPA or 0.001 M EDTA was added, extracted a linearly related (correlation coefficient between 0.87 and 0.99) amount of zinc to that extracted by Mehlich III (a combination of acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and EDTA) and 0.1 N HCl procedures. Yee and Broersma (1988) found that DTPA-TEA, Mehlich III and acetic acid-DTPA extractions gave comparable regressions with barley zinc concentrations in a pot study involving a wide range of British Columbia and Alberta soil samples. Steam sterilization of soil was shown to increase the availability of zinc (Wiens 1968). A study of the relationship of metals with soil organic components suggested that zinc was only weakly associated with organic components since most of the zinc was removed in a 0.1 N HCl extract (Cross

Table 2 Total above ground alfalfa yield and 1 N KCl extractable zinc from Fraser Valley soils limed to specific base saturations (adapted from John, Case and Van Laerhoven 1972)

Soil	Liming treatment	Yield (g/pot)	Soil Zn (ppm)
Ladner	No lime (40% sat.)	5.7	20.1
	To 70% base sat.	19.9	5.3
	To 100% base sat.	22.7	0.3
Hazelwood	No lime (30% sat.)	8.3	15.4
	To 40% base sat.	14.1	14.0
	To 70% base sat.	20.2	0.8
	To 100% base sat.	24.7	0.01
Monroe	No lime (63% sat.)	13.7	6.8
	To 70% base sat.	22.9	5.0
	To 100% base sat.	25.2	0.4
Fairfield	No lime (46% sat.)	8.6	14.0
	To 70% base sat.	16.7	3.6
	To 100% base sat.	23.0	0.2
Whatcom	No lime (20% sat.)	9.7	3.0
	To 40% base sat.	12.1	1.2
	To 70% base sat.	19.5	0.5
	To 100% base sat.	18.8	0.4
Marble Hill	No lime (24% sat.)	7.4	2.2
	To 40% base sat.	12.9	1.2
	To 70% base sat.	10.6	0.4
	To 100% base sat.	14.1	0.02
Annis Muck	No lime (22% sat.)	17.8	28.3
	To 40% base sat.	21.7	16.5
	To 70% base sat.	23.8	3.3
	To 100% base sat.	23.0	1.0

1975). Kowalenko (1991) found that zinc extracted from soil by a chelate (DTPA + TEA + $CaCl_2$ at pH 7.3) consistently did not change from fall to spring over three winters in six fields of Monroe soil growing forage corn or grass. There was evidence that the zinc contents of the two fields growing corn increased, whereas they did not change consistently from year to year in the four grass fields. The corn fields were manured, whereas the grass fields were not, which may account for the increase in zinc content and/or availability.

Several reports have documented the total zinc content of a range of Canadian and British Columbia soil samples (Chae and Lowe 1976, McKeague, Desjardin and Wolynetz 1979, McKeague and Wolynetz 1980) but the data is too limited to make any conclusions about the zinc status of coastal soils. Warren et al (1971) analyzed vegetables grown on British Columbia soils as a method of determining contamination by metals including zinc, but the results were too variable and insufficient to allow general conclusions. A number of studies have examined zinc contents of soils and associated plants, with a concern for potential toxicities but most of them were related to contamination from amendments such as sewage sludge (John and Van Laerhoven 1972, 1976, Warren 1975, John 1976). Luttmerding (1981) included a few zinc analyses in a soil survey report but unfortunately the method of measurement (likely extractable zinc) was not documented nor were the values interpreted. Wolterson (1989) measured total zinc concentrations from 94-183 ppm in Marble Hill and Abbotsford soil profiles that had different raspberry management histories. The concentration of zinc decreased down the profile and there was some evidence that applications of poultry manure, compared to inorganic fertilizer, increased total zinc in the soil.

A number of studies have reported zinc analysis of plant, soil and/or amendment as an incidental rather than primary data. The reason for including the values was usually to determine if zinc resulted in a deficiency or excess problem or would otherwise help interpret the results. Zinc was present in all four of the materials compared in a study of furnace slag as a soil amendment (Beaton, Speer and Harapiak 1968). The zinc content ranged from 5 ppm in an agricultural lime to 270 ppm in a furnace slag. The pot study used Alouette and Pitt soils and showed plant responses to the amendments but the possible role played by zinc, or other nutrients in the amendments, was not determined. This work does show that the inherent zinc content of these materials may be important since liming materials are usually applied at relatively high rates and they tend to reduce the availability of the zinc in the soil. Lime application reduced the zinc concentration in pea stem from 47 to 32 ppm in a pot study using soil from the Ladner area (Eaton and John 1971). Zinc was one of several nutrients that appeared to increase in availability in Lumbum muck soil after it had been fumigated (Maurer and John 1971). Verzosa (1988) found that zinc concentration varied with manganese treatment in both forage and sweet corn grown in a sand culture system. There was an inverse relationship between these nutrients for sweet corn but a positive relationship, at least at lower manganese concentrations, for forage corn. Kowalenko (1989) found, in a sand culture study, that nutrient solution without manganese did not affect the zinc concentration of nor uptake by cauliflower and broccoli. The lack of a zinc effect may have been because growth of cauliflower and broccoli was not affected by the manganese treatments.

Bomke and Lavkulich (1975) reported the zinc content of poultry manure (ranging from 230 to 635 ppm) and of plants (bluegrass, orchard grass and raspberries) grown on heavily manured soils. The contribution of manure zinc to the plants cannot be evaluated because no control (non-manured) plot was included in the study. Bomke and Lowe (1991) found, in a pot study, that zinc concentration of and uptake by an orchardgrass-ladino clover sward increased when the application of deep-pit poultry manure was increased from 0 to 40 t/ha. The manure contained 252 ppm zinc. Safo (1978) measured, in a pot study, an increase in zinc uptake by corn when poultry manure was applied at 20 t/ha but a decrease when the rate was increased to 40 t/ha. On the other hand, leaching losses of zinc tended to be reduced at 20 t/ha rate of manure but increased at 40 t/ha. Fractionation of the soil organic matter into humic and fulvic acids suggested that zinc tended to be associated with the fulvic fraction of the organic matter of the soil. Kenney (1983), examining the possibility of using earthworms as biological indicators for metal contamination from sewage sludge applications, concluded that earthworms tend to regulate zinc absorption and therefore would make poor zinc indicators. The zinc from the milorganite sludge did appear to accumulate in the earthworm since the concentrations were higher in body tissue than in the faeces. Wolterson (1989) found that available zinc, extracted by Mehlich extraction, was higher in a raspberry filed soil that had a history of poultry manure application compared to a field that had inorganic fertilizer application. However, this comparison involved samples from two fields of the same soil (i.e. Abbotsford soil).

There have been variable responses by different crops in the south coast to zinc application, ranging from no response to both yield and quality responses. The pH of the soil has been shown to be an important factor in most cases since the availability of zinc decreases as soil pH increases. Several relatively detailed soil-oriented studies have shown that it is potentially possible to chemically extract available zinc, which could be used for fertilizer recommendations. However, the studies have not examined a sufficiently wide range of soil types, crops or field conditions to define a workable system. Soils in the south coast tend to be somewhat acid and undergo relatively quick acidification, therefore zinc recommendations based on soil tests must be adjusted if management practices (i.e. limestone applications) will affect soil pH. Little attention has been directed to zinc toxicity, a possibility that may occur as soils become more acid or from zinc applications (as fertilizers or with other amendments such as limestone, manure or sludges) or a combination of the two factors. Negligible work has been done on the most appropriate method of application (e.g. form, rate, timing, placement) for those situations that require zinc supplementation.

INTERIOR - HORTICULTURE

The first evidence that their was a concern about zinc deficiency in horticultural crops in the interior of the province was a study reported by McLarty (1936) more than fifty years ago, when the quality of apples grown in the Okanagan had been noted to have had drought spot and corky core. In an effort to determine the cause of the problem, zinc was one of a number of treatments injected into apple trees. A number of years later, however, Woodbridge (1951) observed visual symptoms ("rosette or whorl, little leaf and die back") on apple trees that were assumed to be due to zinc deficiency. The symptoms were observed on individual limbs of a single tree as well as on entire trees in an orchard. Zinc concentrations of visually deficient (3 to 22 ppm) and healthy (6 to 40 ppm) leaves unfortunately overlapped. The deficiency was subsequently observed on pear, cherry, peach, apricot and prune (Woodbridge 1954). Analysis of zinc in various tissue (leaves and twigs) of the different fruit trees tended to be lower for tissue associated with a greater degree of visual deficiency than those with none. Treatments, such as foliar and dormant sprays using sulphate and oxide forms of zinc, were tested and a dormant spray of zinc sulphate was concluded to be the most successful to reduce deficiencies. In most cases a single application was sufficient for several years but in severe deficiency instances, sprays in successive years were recommended. Wilks and Stewart (1961) found that dormant zinc spraying, especially using zinc sulphate or zinc chelate (EDTA), tended to offset but did not cure some of the effect of little-cherry viral disease in the Creston Valley. Leaf tissue analyses appeared to be of limited usefulness in this situation, since the virus disease tended to influence visual zinc deficiency symptoms. Hess (1971) concluded that zinc did not limit onion production in the Okanagan, however, it was recognized that further study would have to be done to confirm the conclusion. Zinc deficiencies were considered to be common in interior orchards by the late 1970s (Swales 1979).

As a result of the evidence for zinc deficiencies in tree fruits in the Okanagan, studies have also been conducted on treatment methods. Initially, emphasis was on foliar application. Ashby (1969) showed that zinc was absorbed readily by leaves. Although zinc sulphate was observed to be a suitable foliar application method, some potential problems with the method were observed. Concentrations as low as 400 ppm zinc sprayed on leaves in June have been observed to cause russeting and fruit quality damage to Golden Delicious apples (Neilsen and Hoyt, personal communication). For this reason, chelated zinc applications are generally recommended in non-dormant periods. The application of $ZnSO_4$ during dormancy can cause bud damage during cool, wet weather when applied with dormant oil. Thus it is recommended that $ZnSO_4$ should be applied and allowed to dry immediately prior to the application of dormant oil (B.C. Min. of Agric. and Fisheries 1989). Mason, Gardiner and Sanderson (1972) found that zinc in dimethyldithiocarbamate sprays (45% zinc) was fairly readily absorbed by the leaves. The study did not, however, compare the effectiveness of this spray treatment with other methods nor its effect on plant growth. Zinc in chelate or mineral form were equally effective as foliar treatment for zinc deficient apple seedlings if the same amount of zinc was applied (Neilsen and Hogue 1983). Zinc chelate foliar application was used to correct an apparent zinc nutrition concern in an orchard floor management study (Neilsen, Meheriuk and Hogue 1984). Recent results on Delicious apple trees indicated little difference in the effectiveness of $ZnSO_4$ at silver tip or postharvest, or sprays of ZnO or chelated zinc at tight cluster in increasing leaf zinc concentrations immediately nor residually (Neilsen and Hoyt 1990). In contrast, zinc applied to the surface of a loamy sand or within peat plugs inserted in the soil increased leaf zinc, sometimes to toxic concentrations (>120 ppm). These later results imply that the application of appropriate soil zinc at planting time might reduce the need for foliar zinc sprays, but must be investigated for the length of the effect over a range of soil types. Leaf tissue analysis has been readily accepted as a means of indicating zinc deficiencies in Okanagan orchards for many years (Swales 1979).

By 1985, leaf tissue analysis was being used for diagnosing zinc deficient orchards (B.C. Min. of Agric. and Food 1985b) and vineyards (B.C. Min. of Agric. and Food 1985a). Adequacy of zinc was assumed when foliar zinc was above 20 ppm for apples, 14 ppm for pears, and 16 ppm for other fruit trees. For grapes, adequacy ranges for zinc petiole concentrations at bloom time were set at 20-30 ppm for labrusca or hybrid grapes and 25-100 ppm for vinifera grapes. The basis for the adequate tissue values was not documented but was probably developed from local published and unpublished information and extrapolation from general literature data. Several reports have documented research on factors which influence leaf tissue zinc concentrations. Ashby (1969a) showed that washing leaves was important to obtain proper results and concluded that "a detergent wash and two rinses effectively removed most of the nutrient element deposits from leaf surfaces in all three tree-fruit species". Jonker (1986) concluded that differences in the strain of "Delicious" apples did not influence zinc (and other nutrient) concentrations. Leaf zinc concentration was found to be affected by the phosphorus nutrition of "McIntosh" apple, at least in solution culture, with extremely high tissue phosphorus concentrations associated with zinc deficiency (Neilsen and Hogue 1986). This effect was attributed to low silicon levels in nutrient solution culture. There was little field evidence for a P X Zn antagonism for "Foch" grapes (Neilsen, Stevenson and Gehringer 1987) and for apples when high applications of planting hole phosphorus was made (Neilsen, Hogue and Yorston 1990). A nutrient solution study suggested that leaf zinc concentration of apple seedlings decreased as root zone temperature increased from 12 to 20°C (Hogue and Neilsen 1986), although field measurements of this effect were not consistent (Neilsen, Hogue and Drought 1986). Zinc concentrations in leaves of apples were observed to decline steadily (40 to 15 ppm observed) during the growing season (May - July) and this decline occurred despite annual treatments with a dormant spray (Neilsen 1988). Hogue and Neilsen (1988) assumed that midsummer zinc concentration of 24 ppm of mid-terminal extension leaves indicated adequate zinc nutrition.

Research on the potential for using soil analysis to examine the zinc status of orchards has been conducted but has tended to be more recent. Hess (1971) concluded that 1.08 ppm zinc extracted by DTPA from Okanagan soils "does not indicate a likely deficiency". This conclusion resulted from a study of onion fields where both soil extraction and plant analyses were compared with literature values. Zinc in DTPA soil extracts and onion tissue were assumed, from literature values, to be deficient at concentrations less than 0.8 and 8.0-9.3 ppm, respectively. A general soil zinc availability study by John (1972) provided useful comparative provincial information but, because the test crops were corn and oats as studied under pot conditions, the results should only be applied to tree fruits with caution. A study more specifically on orchard soils included sequential fractionations of zinc as well as independent extraction of exchangeable zinc with 1 M ammonium acetate at pH 7.0 (Neilsen, D., Hoyt and MacKenzie 1986). Total zinc in the 20 soils examined varied considerably (51 to 226 ppm) as did the proportions of the total that was measured as exchangeable (<1 to 23% of total extracted with M $MgCl_2$), organic matter associated (<1 to 30%), iron and aluminum oxide associated (1 to 15%) and manganese oxide associated (6 to 24%). Residual zinc accounted for 46 to 92% of the total measured. All the fractions, except for that associated with iron and aluminum oxides which was not compared, were positively correlated with total zinc (r = 0.71 to 0.96), organic matter content (r = 0.46 to 0.82) and Bray P1 extractable P (r = 0.45 to 0.77). On the other hand, there were negative correlations between exchangeable and organic matter associated zinc with pH (r = -0.53 to 0.61) and with residual zinc (r = -0.70). The authors concluded from the various relationships that soil zinc was redistributed from the residual fraction to that associated with the organic and exchange fractions. The ratio of ammonium acetate to magnesium chloride extracted (exchangeable) zinc was negatively correlated (r = -0.84) with pH. At pH 7 the two solutions extracted approximately equal amounts but at pH 4 $MgCl_2$ extracted about seven times as much zinc as ammonium acetate. A greenhouse study on orchard soils (Neilsen, D., Hoyt and MacKenzie 1987), using navy beans as the indicator crop concluded that magnesium chloride was a more suitable extractant for available zinc than acid (0.10 M HCl), chelate (DTPA) and mixed acid (Mehlich I consisting of 0.05 M HCl and 0.0125 M H_2SO_4). Modification of the concentration of the magnesium chloride (from 1.0 to 0.01 M) and extraction ratio altered the correlation with crop zinc concentration and uptake. A concentration of 0.25 M and 1:2 soil:extractant ratio was suggested as the optimum extraction for recommendation and operational considerations. The study included comparisons with soil pH, organic matter, extractable P and various sequential extractions of zinc. Although soils were selected to include a wide range of available zinc, amendment of the soils with zinc did not increase the yield of beans. In a field study comparing 0.25 M $MgCl_2$ and DTPA extractable zinc from soil with leaf zinc and P:Zn ratios, relationships were generally poor, but the magnesium chloride extraction showed most promise (Neilsen, D., Hoyt and MacKenzie 1988). Leaf zinc concentration did not appear to be as useful as visual symptoms for diagnosing deficient orchards. Considering these factors and the problem of leaf contamination, it was suggested that soil analysis (0.25 M $MgCl_2$) could be a useful diagnostic technique. Soil analyses with 0.25 M $MgCl_2$ extractant did appear to confirm low to medium zinc availability in a study of leaf zinc concentrations (Neilsen 1988). Although $MgCl_2$ appears to be more favourable as an extractant for soil available zinc, some research on the potential usefulness of multiple element extractants has been conducted (Van Lierop 1987, Yee and Broersma 1988), but the data is still too limited for definitive conclusions. Total zinc analyses may be useful for identifying contaminated soils (Warren et al 1971, Warren 1975), but more information would be needed. The inherent zinc content of soils possibly shown by parent material zinc content (Chae and Lowe 1976), may be useful information in this case.

Zinc nutrition has also been considered when various other orchard management practices have been studied. Although an outdoor sand culture study showed that increased calcium can reduce the zinc concentration of apple leaves (Mason and McDougald 1974), this does not always mean that leaf zinc concentration would change with changes in soil pH in the field (Neilsen, Hoyt and Lau 1982). Fruit removal decreased subsequent leaf zinc concentrations (Jentsch and Eaton 1982). There have been variable zinc responses to different orchard soil management practices such as tillage, plastic mulching or herbicide applications with factors such as soil temperature, competition for nutrients, etc. contributing to the type of effect measured (Neilsen and Hogue 1985, Hogue and Neilsen 1986, Neilsen, Hogue and Drought 1986, Hogue and Neilsen 1988). In practice, it has been generally difficult to identify a consistent effect of orchard floor vegetation management on micronutrient nutrition, including zinc (Hogue and Neilsen 1987). Most of these studies have concentrated on macro- rather than on micro-nutrients. Less frequent irrigation was found to decrease leaf zinc concentration of apple, suggesting that zinc nutrition problems may be aggravated under conditions of water stress (Neilsen and Stevenson 1986). Zinc deficiency has been pronounced but not directly attributable to irrigation with high pH wastewater used to irrigate vegetables (Neilsen et al 1989), apples (Neilsen et al 1989) or sweet cherry fruit trees (Neilsen et al 1991).

Zinc deficiency symptoms have been identified on most of the important horticultural (tree fruit and vine) crops in the southern interior during the past 40 years. As a consequence, foliar spray technology for zinc has been developed with respect to the most effective form, rates and time of spray application of zinc. Thus, zinc sprays are routinely made each year in most orchards regardless of any objective measurement of orchard zinc status. This approach seems to be confirmed by the chronically low (<20 ppm) mid terminal, mid season leaf zinc concentrations observed in most orchards and recent research suggesting little residual effect from spray applications of zinc. Applications of high rates of phosphorus at planting time and variations in orchard floor vegetation management systems seem to have little negative effect on tree zinc nutrition. High summer soil temperatures and low irrigation frequency are not conducive to optimum zinc uptake. Only recently has much attention been given to soil zinc status in this area, with measured soil zinc fractions showing considerable variation in a survey of orchard soils. A 0.25 M $MgCl_2$ extractable zinc test seems promising as a measure of orchard zinc status, but has not been tested widely nor used to systematically delineate variations in the zinc supplying capacity of orchard soils. This would seem important in an area with chronic zinc deficiency, possible overuse of zinc in some situations and where application of zinc in irrigation waters (fertigation) is being considered.

INTERIOR - FORAGE

Although Mason (1964) reported some preliminary results that showed that an application of zinc increased the yield of alfalfa from 1061 to 1285 kg/ha at Armstrong, final results do not appear to have been reported. Several subsequent studies did not observe a yield response to micronutrient treatments that included zinc. For example, Pringle and Van Ryswyk (1965) used fritted trace elements on peats from the Williams Lake and Miocene, Freyman and Van Ryswyk (1969) used Long Ashton solution on pinegrass on Grey Wooded soils and Ashby (1969b) used polyethylene encapsulated zinc on an Osoyoos soil. Lowe and Milne (1979) concluded from soil and plant analysis data that the Vanderhoof-Fort Fraser soils they studied were adequate in zinc. Similarly, Broersma and Van Ryswyk (1979) concluded that irrigated corn grown on Fleetwood soil in the Kamloops area was adequate in zinc, according to plant analyses, and that the visual deficiency observed was due to magnesium. More recently, corn has been shown to respond to zinc application on a soil on the Kamloops Research Station (Van Ryswyk and Mir 1988, Van Ryswyk 1989). Bomke and Lowe (1991) showed in a pot study, using a clay soil from near Prince George, that the zinc concentration of barley was increased by the application of deep-pit poultry manure containing 252 ppm zinc at rates up to 40 t/ha. The yield of barley was dramatically increased by the application of manure, but the specific role of the zinc in the manure on this response was not determined.

Thesis studies such as those by Gregory (1947) which studied the effect of minor elements on red clover root nodulation, Kynaston (1953) which studied the effect of micronutrients on seed germination, or Ruckle (1977) which studied analyses of vegetation and soils near Celista, provide useful basic information but do not determine the zinc status of soils in the interior. Likewise, province-wide or general studies which included assessments of the zinc content of interior soils (John 1972, Boojedhur 1975, Chae and Lowe 1976, Runka 1972, Cotic, Van Barneveld and Sprout 1974, Lord and MacKintosh 1982, Lowe and Bomke 1982, Van Lierop 1987, Lord and Green 1986, Dawson 1989, Yee and Broersma 1988) do provide some information for possible extrapolation to a wider area of the interior, but relationships between the soil analysis and plant response to zinc application are needed.

Considerable work has been reported on the analyses of forage materials in the interior, with reference to quality for animal production, and most show that the zinc concentration was frequently below that which was considered adequate and zinc supplementation of feeds has been recommended (Miltimore 1967, Fletcher and Brink 1969, Miltimore, Mason and Ashby 1970, Mason and Miltimore 1972, Tingle and Dawley 1972, Van Ryswyk, Hubbard and Miltimore 1973). One study found that, although the zinc content of forages were low, zinc supplementation did not affect growth of beef animals (Pringle, Dawley and Miltimore 1973). They suggested that, in their study, zinc reserves in the animal contributed to the lack of response to supplementation of the feeds with zinc. Van Adrichem and Tingle (1975) found that zinc concentration of meadow foxtail increased in cases where nitrogen increased yield. This suggests that the effect of various nutrient management practices must be considered when evaluating forage quality in the interior, particularly when the zinc content is deficient or marginal for livestock production. A number of reports that have included zinc analysis data for forage materials provide some data for extrapolation over a large area of the interior and for assessing possible trends over time (Miltimore et al 1973, Miltimore, Kalnin and Clapp 1978, B.C. Min. of Agric. 1978, Anonymous 1984a, 1984c, 1984d, Soder 1984). Chuah (1990) has observed "more and more low values of soil zinc" when the results of DTPA extract analyses from soil samples analyzed at the test laboratory were examined.

A number of studies have suggested that there can be instances of excessive zinc (Warren et al 1971, Warren 1975, John, Van Laerhoven and Cross 1975, John, Van Laerhoven and Bjerring 1976, Natsukoshi 1979, Haak 1980). These tend to be localized cases associated with industrial activities and would have limited influence on most of the livestock production in the interior.

It appears from the crop response data and forage analysis, that the zinc contents of many soils in the interior of the province tend to be adequate for crop growth but deficient for providing adequate zinc for livestock production. Considering the large areas of grazing involved, it would appear that direct supplementation of the animals would be more suitable than zinc fertilization. Zinc fertilization may be practical in more intensively used areas such as for production of winter feed. However, more systematic research data are required to confirm this conclusion.

PEACE RIVER

Very little research has been reported in relation to the zinc status of the Peace River region of British Columbia. The survey report by Miltimore, Mason and Ashby (1970) does not specify information for this area, but it is implied that samples from the Peace River were included since samples were said to be from "throughout British Columbia". Pringle, Dawley and Miltimore (1973) state that "barley and forage grown on Grey Wooded soil of the Peace River area, even though analytically low in Cu and Zn, are sufficient for heifers on full feed". The study involved a feeding trial conducted at Prince George. This is similar to the data on analysis of feed samples submitted to the provincial feed laboratory which indicated that feeds from the Peace River area tend to be higher than most of the rest of the province but the data are quite variable and limited for definitive conclusions (B.C. Min. of Agric. 1978, Anonymous 1984e, Soder 1984). General soil and plant research which included Peace River soils or soils of similar characteristics (Gregory 1947, Kynaston 1953, John 1972, Chae and Lowe 1976, Van Lierop 1987, Yee and Broersma 1988) is likewise very limited and not sufficiently specific for the Peace River for firm conclusions on the zinc status of the area.

More systematic information is required to determine the relative priority for research studies on zinc in the Peace River area. If limestone applications to increase the pH of acid soils in the area become frequent, the effect on zinc availability should be considered.

SUMMARY

Aside from the Peace River area, research work has shown that zinc deficiency occurs in many parts of the province. Work on zinc for the Peace River area is almost negligible. Zinc deficiency has been fairly extensively researched for tree fruit in the Okanagan to the point where leaf tissue standards are being used and foliar spray procedures defined. However, more recent work on soil analyses shows the need to understand basic soil and plant zinc relationships. Research in the south coast of the province has documented instances of zinc deficiency for the intensively grown crops of that region, but the work has not progressed sufficiently to provide a basis for making recommendations nor defining optimum methods for zinc applications for deficient situations. The importance of the effect of soil pH on zinc availability has been confirmed, therefore zinc fertilizer recommendations will have to take into account management practices, such as liming, that alter pH. With increased interest in and use of zinc fertilizer in the Okanagan and the south coast, together with soil pH changes due to gradual soil acidification and liming, instances of zinc excesses and toxicity will likely become more important. In the interior, it appears that zinc is at least sufficiently low in many cases to result in poor livestock feed quality, but possibly not low enough to reduce plant growth. If that is the case, zinc deficiency in livestock operations may best be treated by direct supplementation of feeds rather than fertilizer applications to plants. However, more research would be required to make firm conclusions.

MANGANESE

SOUTH COAST

There has been an interest for many years in determining whether the manganese present in south coastal soils is sufficient for crop production and periodic reviews have been made of available information (Stokvis 1939, Hill 1949, Day, Farstad and Laird 1959, John 1971). These reviews suggested that both manganese deficiency and toxicity occur. In an early pot study with clover, a response to manganese was suspected but the variable size of pots used made interpretation of the results questionable (Tamura 1941). In that study, soil manganese was extracted by the Spurway method. In a study on three soil types with carrots and turnips as test crops, Harris (1943) reported increased yield and storage quality of turnips after manganese application on Milner soil. Also, with carrots, manganese application on a peat soil increased storage quality and root to top ratio. Raspberry dry weight yield, carbohydrate content and vitamin C were increased by application of manganese in a field plot at the University of British Columbia (Harris 1944). Previous examination of "displaced soil solutions" and sterilization of soil samples from raspberry fields had created "a suspicion of Mn deficiency" (Harris 1937). Micronutrient applications (possibly manganese) were implicated in resistance to mosaic disease by raspberries (Harris 1940). Atkinson and Wright (1942), however, had previously reported that they could see no general relationship between exchangeable manganese in soils and "good" versus "poor" raspberry growth and production in an area near Hatzic. Whitehead (1951) reported that excessive manganese applications together with different mulches were "detrimental" to growth of strawberry plants. Two thesis reports showed various effects of manganese on quality aspects of radishes (Wiens 1949, Power 1950). In another study, late blight on tomatoes negated any definitive conclusions that could be made on manganese (Larson 1949). Several non-soil or artificial soil studies were conducted to derive basic information including studies on strawberry (Gold 1959), cucumber (Magel 1951), tomato and wheat (White 1940), and also the effect of manganese on the germination of forage seeds (Kynaston 1953). The data of these early studies showed that more research under south coastal soil and crop conditions was needed to determine the actual requirement for manganese applications and management.

In the last twenty years there have been various studies reported that have included some research on manganese, but only a few have specifically focused on the manganese status for crop production in south coastal British Columbia. Most of these studies included lime applications or at least some consideration of soil pH. Maas (1975) reported that organic soil samples from Vancouver Island were not deficient in minor elements, and lime did not result in growth response when sunflower was used as a test crop in a growth chamber pot trial. Eaton and John (1971) conducted a pot trial with peas on a Ladner area soil which was "suspected to be deficient in Mn". The study did not actually document a manganese deficiency, but liming (which increased the height of plants, the number of nodes and dry weights of leaves and stems) unexpectedly increased the manganese concentration in the pods. Gill (1983) conducted trials to examine the requirement for manganese by broccoli and brussels sprouts but did not detect a response to foliar manganese application. Some of the soils used had been limed but the pH never exceeded 6.5. The lack of response by these two crops to manganese application should be extrapolated to other crops with extreme caution since Kowalenko (1989) showed in a sand culture system that broccoli and cauliflower were quite insensitive to low manganese supplied by a nutrient solution whereas oats and sweet corn in the same system were quite sensitive. On the other hand, Verzosa (1988) could not induce manganese deficiency in forage and sweet corn in a similar sand culture system. Manganese toxicity of cucumbers grown in a hydroponic system was attributed to the release of manganese during the decomposition of the sawdust used as the rooting medium (Freeman 1981). A field trial at Agassiz Research Station that was designed for a different purpose, showed that high rates (up to 44 t/ha) of limestone application probably resulted in decreased oat growth because of an induced deficiency of manganese and/or zinc (Kowalenko, Maas and Van Laerhoven 1980). This conclusion was made from plant analysis data which showed manganese and zinc at apparently deficient concentrations according to other literature reports. A follow-up study to examine lime induced manganese and/or zinc deficiency has not shown an induced manganese deficiency (Kowalenko 1980a, 1980b, 1983, 1984a), but the test crop, cauliflower, may have been a poor choice for examining manganese deficiency (Kowalenko 1989). The field trial is continuing but the test crop has been changed from cauliflower to oats to examine the manganese status more sensitively. Several studies have included some manganese measurements in forestry (Carter, Otchere-Boateng and Klinka 1984, Carter, Scagel and Klinka 1986, Davis 1987) but no conclusions can be made from this limited information. Recently, however, Gadziola (1991) reported a growth and leaf manganese response by western hemlock to soil applied manganese applicationsin Maple Ridge and Chilliwack area forests.

Besides a concern for manganese deficiency, several studies have focused on the possibility of manganese toxicity in south coastal soils. The beneficial effects of liming acidic soils for alfalfa growth was assumed to have been partly due to reductions of toxic quantities of manganese (John, Case and Van Laerhoven 1972, John et al 1972). Plant tissue analysis supported the conclusion as there were considerable reductions of manganese concentrations as lime rate increased. South coastal soils were included with soils from other parts of Canada in a study of manganese and aluminum availability (Hoyt and Webber 1974). The major concern was toxicity of these elements.

For perennial crops, leaf tissue sampling is frequently used as a means for determining nutrient requirements. In south coastal British Columbia, some work has been conducted on leaf tissue analyses for strawberries, raspberries and filberts (hazelnuts). Initially a survey was conducted to assess the general status of nutrients of raspberries in the lower Fraser Valley (John, Carne and Eaton 1971), but subsequent studies have shown that many factors including genotype, date of sampling, type of tissue sampled, etc. (John and Daubeny 1972, John, Daubeny and Chuah 1976) must be taken into consideration for proper interpretation of nutrient concentrations. Kowalenko (1981b) showed that most nutrient concentrations in raspberry leaves vary considerably with time. Manganese concentrations in new cane leaves were relatively stable in July, therefore, July sampling may have potential for development of a leaf-tissue-based recommendation system. However, relationships between new cane leaf manganese concentration and the crop's requirement for this nutrient have not yet been derived. Similar studies have been conducted on strawberries but, as with raspberries, only the importance of sampling factors (time, type of tissue, genotype) have been examined (John, Daubeny and McElroy 1975, John et al 1976), therefore, the relationship between the nutrient status and crop yield response has not been derived. Although the concentration in filbert leaves was shown to be suitably stable from mid-August to mid-September (Kowalenko and Maas 1982b), and that washing the leaves was essential for diagnostic purposes (Kowalenko 1984d), a target concentration to guide fertilizer application could not be derived for manganese with the information available (Kowalenko 1984c).

A survey of the manganese concentrations in feed for ruminants throughout British Columbia concluded that, although many types of feed had very high concentrations of manganese, there were some cases where manganese supplementation was proposed (Miltimore, Mason and Ashby 1970). This supplementation was recommended for areas where "legume hays and corn silage" are fed. There have been several summaries of analyses of feeds which include manganese (B.C. Min. of Agric. 1978, Anonymous 1984b, 1984f, Soder 1984) which have provided average values, ranges, etc. and comparisons with other regions. More rigorous examination of feed quality for Fraser Valley dairies did not identify manganese as a particular problem for herd performance (Peterson and Waldern 1977, Cathcart, Shelford and Peterson 1980). The latter study found that manganese concentration tended to be high and related to soil pH and/or influenced by soil contamination of the sample. Since there was considerable variation of manganese in feeds and liming soils is a standard practice, it should not be generalized that manganese would be consistently high in feeds in south coastal British Columbia.

The response of plant and soil manganese to a variety of amendments has been included in a number of studies which included plant or other analyses. Beaton, Speer and Harapiak (1968) used south coastal soils, Alouette and Pitt, in a growth chamber study to examine the possible use of electric furnace slag as an amendment. The slag resulted in a "marked beneficial effect" on red clover growth which was attributed largely to its calcium and magnesium content. It was also speculated that micronutrients may have had an effect. Although the manganese contents of the liming materials were determined (0.004 to 0.31% Mn), no measurement of micronutrients in soil or plant samples were reported. Fumigation of a Lumbum muck soil in which carrots were grown was shown to increase manganese concentrations in both the leaves and roots (Maurer and John 1971). The application of $Pb(NO_3)_2$ increased the manganese content of oat tops in a growth chamber study using Hjorth soil (John and Van Laerhoven 1972). Cadmium was observed to influence tissue manganese concentrations of oats and lettuce in culture solutions, which resulted in the conclusion that there was "a complexity of elemental interactions" (John 1976). Bomke and Lavkulich (1975) included manganese analysis of grass and raspberry tissue in response to manure applications, however, crop growth was not included in this report. Safo (1978) observed a general increase in manganese uptake by corn in a greenhouse trial with Grigg and Monroe soils when poultry manure was applied. In two situations, however, there was a decrease in uptake as the rate of manure was increased from 20 to 40 t/ha. The increased rate of manure application, however, resulted in more manganese leaching. Recently, Bomke and Lowe (1991) also found that the manganese concentration of orchardgrass-ladino clover forage decreased as the rate of deep-pit poultry manure increased. The decreased manganese concentration was not entirely due to dilution as a result of increased yield, since the yield increase was not as great when the rate of manure increased from 10 to 40 t/ha. The manure itself contained 271 ppm manganese. A considerably higher manganese concentration was found in the orchardgrass (178 ppm) than in the ladino clover (57 ppm). Although sewage sludge increased the yields of lettuce and beets in a pot study using Monroe soil, the precise factor or factors (manganese, other elements or physical effects) leading to this response could not be determined from the analyses (John and Van Laerhoven 1976). It was observed that manganese (and other nutrients) "were not simply or solely dependent upon the resultant sludge-borne heavy metal contamination of the soil but a complexity of factors". Yole (1980) observed an increase in mustard-spinach growth when Iona sludge, but a decrease when Wondergreen (a commercially obtained sludge), was added to a sandy loam soil (pH 5.3) in a greenhouse study. Leaf tissue manganese increased with an increasing rate of Wondergreen but did not increase with Iona sludge. It was postulated that excessive salinity or copper, iron or manganese in the Wondergreen product caused the poor plant growth. Boron application tended to decrease the manganese concentration of spinach and corn (John, Chuah and Van Laerhoven 1977), while nitrogen and, to a lesser extent, potassium applications increased leaf manganese of filberts (Kowalenko and Maas 1982a).

Soil solution extraction as a method for determining the manganese status in soil-plant studies was commenced more than fifty years ago when Harris (1937) measured manganese in "displaced soil solutions" in soils from fields producing low yields of raspberries. Quantities of manganese measured in the extraction were very small and it was concluded that "one would hardly expect the beneficial effects of sterilization to be due to increased manganese availability". It was, however, expected that the acid soils should have had larger manganese quantities and this resulted in "a suspicion of manganese deficiency". Atkinson and Wright (1942) found that steam sterilization increased exchangeable manganese of soils, but no definitive cause(s) for the poor compared to the good raspberry production areas were determined. Tamura (1941) considered a Spurway extraction in a micronutrient study but the interpretation of the results were suspect because of the variable pot sizes used in the study.

Renewed research on soil fertility issues involving soil extraction occurred in the 1970s. John, Carne and Eaton (1971), in an attempt to evaluate the nutrient status of raspberries, reported correlations between leaf tissue concentrations and some soil analyses. A soil extraction for manganese was apparently not done, but significant negative correlations were observed between leaf manganese concentration and soil pH ($r = -0.39$) and also extractable magnesium ($r = -0.43$). Since these relationships have not been studied further, their significance cannot be fully evaluated given the variability of raspberry leaf manganese concentration with factors such as date of sampling, etc. discussed earlier.

The limited data reported on spinach and corn growth and leaf manganese concentration in a boron pot study suggest that N KCl extractable manganese is not a very promising soil test (John, Chuah and Van Laerhoven 1977), since extractable soil manganese for Marble Hill versus Monroe soil did not reflect large differences in plant uptake between these two soils (Table 3). It is also unclear from the report whether the manganese extraction was done before or after the liming of the soils.

Table 3 Comparison of manganese extracted by N KCl with plant yield and manganese concentrations (zero boron treatments) for three south coastal British Columbia soils (adapted from John, Chuah and Van Laerhoven 1977)

Soil		Spinach			Corn		
Name	Mn extracted (ppm)	Dry wt. (g/pot)	Mn (ppm)	Mn (mg/pot)	Dry wt. (g/pot)	Mn (ppm)	Mn (mg/pot)
Annis muck	115	4.42	556	2.46	3.03	123	0.37
Marble Hill	30	1.22	204	0.25	3.61	176	0.64
Monroe	32	0.61	60	0.04	3.85	35	0.13

In a pot study where poultry manure was applied to two Fraser Valley soils (Grigg and Monroe), Safo (1978) concluded that a greater proportion of metals, including manganese, was associated with the fulvic than humic acid fraction of the soil organic matter. Yole (1980) found that DTPA extractable manganese increased with the application of increasing rates of two different sewage sludge materials. Kowalenko, Maas and Van Laerhoven (1980) observed that neutral normal ammonium acetate extracted consistently less manganese (2.5 versus 5.0 ppm) as soil pH increased from 5.2 to 6.4 after limestone applications had been increased from 0 to 44 t/ha. This decreased extraction of manganese also corresponded to decreased oat yield, straw and grain manganese concentrations and plant manganese uptake. This same soil extract for manganese was also observed to be correlated with leaf manganese concentrations of filberts and the correlation was significant over several year and cultivar combinations (Kowalenko and Maas 1982a). The filbert trial did not include a manganese treatment but several of the nutrient amendments, especially lime, potassium and nitrogen, influenced soil pH and apparently also leaf manganese concentrations. Soil manganese and pH values also appeared to be related, but this specific correlation was not reported. Gill (1983), in contrast, reported that leaf manganese concentrations of broccoli and brussels sprouts were not correlated with soil pH. However, as discussed earlier, brassicas may be a poor indicator crop for manganese deficiencies (Kowalenko 1989).

In a pot trial using several British Columbia and some Alberta soils, Yee and Broersma (1988) found that an extraction of manganese with DTPA-TEA provided useful regressions with barley manganese concentrations. They postulated that manganese extracted by Mehlich III (a combination of acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and ammonium acetate) and acetic acid-DTPA extractions were not well correlated with plant manganese because of their acidity. In addition, chelation by EDTA and DTPA is reduced at low pH. Kowalenko (1991) found that manganese in a $CaCl_2$ - chelate (DTPA and TEA at pH 7.3) extraction of forage production (corn and grass) fields on Monroe soil tended to decrease from fall to spring in each of three years, but the decrease was not consistent from field to field. This shows that it is important to consider the time of sampling when interpreting field data and in the development of soil test recommendation procedures.

A few studies have examined potential situations of manganese toxicity such as can occur in acid soils. John, Case and Van Laerhoven (1972) showed that manganese extraction with normal ammonium acetate at pH 4.8 or 7.0, with N KCl and with neutral N ammonium acetate plus 0.2% hydroquinone decreased as soil pH increased due to limestone application to seven Fraser Valley soils (Table 4). Only the ammonium acetate plus 2% hydroquinone extraction showed a significant correlation with alfalfa grown in a pot study, but the correlation coefficient was quite small (r = -0.27). The lack of correlation of the manganese extracts with alfalfa yield was probably influenced by other factors influencing plant growth such as aluminum toxicity. On the other hand, Hoyt and Webber (1974) examined the relationship between various manganese extracts, plant (barley, rapeseed and buckwheat) growth and manganese concentrations in a study of acid soils from across Canada which included coastal British Columbia soils. They found that extractions with calcium chloride (0.01 M for 5 min or 5 days, or 0.02 M for 1 hr), sodium chloride (2 N for 16 hr), phosphoric acid (0.01 N), water and ammonium acetate (1 N at pH 7 or 1 N with 0.2% hydroquinone) were all significantly correlated (r = 0.59 to 0.87) with plant manganese, but recommended that extraction with 0.01 M calcium chloride for 5 minutes would be best for determining plant-available manganese in acid soils that might result in crop manganese toxicity.

A number of studies have been conducted where only the soil was analyzed for manganese to determine relationships among fractions or to understand processes, some of which assume a relationship to plant production. Baker (1950) surveyed 45 surface and subsurface samples from throughout British Columbia (20 from the south coast) for total, ammonium acetate extractable and hydroquinone reducible manganese. Ammonium acetate extraction was assumed to be "available". All the samples were from uncultivated sites, assumed to represent the inherent manganese status of the soil. Available manganese, as determined by ammonium extraction, of the south coast surface samples ranged from 8 to 238 ppm and accounted for 1.6 to 8.4% of the total manganese measured. Hydroquinone reducible manganese of the same surface samples ranged from 12 to 832 ppm. Baker further concluded that British Columbia soils were generally adequately supplied with this nutrient but qualified this by suggesting that deficiency of manganese may occur in specific areas of high pH, low organic matter or situations of ion interference. The pH of the surface samples of south coast soils analyzed ranged from 4.7 to 5.9. Vernon (1951) also analyzed soils for "available and easily reducible " manganese, but noted that the method of drying samples (air or oven) could have influenced the results. Safo (1970, Safo and Lowe 1973) conducted a more

Table 4 Comparison of total above ground alfalfa yield with pH and manganese extracted by N NH_4Ac at pH 4.8 (MNAC), N KCl (MNKCL) and neutral normal ammonium acetate with 0.2% hydroquinone (MNAQ) after plant growth in Fraser Valley soils limed to specific base saturations (adapted from John, Case and Van Laerhoven 1972)

Soil	Liming treatment	Yield (g/pot)	Manganese (ppm) pH	MNAC	MNKCL	MNAQ
Ladner	No lime (40% sat.)	5.7	4.8	12.3	15.3	16
	To 70% base sat.	19.9	5.5	5.2	7.3	12
	To 100% base sat.	22.7	6.3	4.6	4.7	10
Hazelwood	No lime (30% sat.)	8.3	4.8	12.9	18.1	32
	To 40% base sat.	14.1	5.1	8.0	12.3	19
	To 70% base sat.	20.2	6.0	3.5	6.2	29
	To 100% base sat.	24.7	6.8	3.4	4.9	13
Monroe	No lime (63% sat.)	13.7	5.2	28.4	37.9	206
	To 70% base sat.	22.9	5.5	24.4	30.9	207
	To 100% base sat.	25.2	6.6	12.9	6.0	192
Fairfield	No lime (46% sat.)	8.6	5.1	20.3	25.8	133
	To 70% base sat.	16.7	5.9	10.9	10.3	92
	To 100% base sat.	23.0	7.0	8.8	2.9	73
Whatcom	No lime (20% sat.)	9.7	5.4	14.5	18.2	290
	To 40% base sat.	12.1	5.8	9.5	9.6	263
	To 70% base sat.	19.5	6.3	6.0	4.3	187
	To 100% base sat.	18.8	6.8	4.3	2.5	158
Marble Hill	No lime (24% sat.)	7.4	5.6	25.0	29.7	409
	To 40% base sat.	12.9	5.9	15.9	17.2	409
	To 70% base sat.	10.6	6.6	8.5	5.7	263
	To 100% base sat.	14.1	7.1	6.9	3.0	252
Annis Muck	No lime (22% sat.)	17.8	4.4	43.0	114.5	95
	To 40% base sat.	21.7	5.0	26.6	39.9	83
	To 70% base sat.	23.8	5.7	13.9	9.3	70
	To 100% base sat.	23.0	6.1	17.2	7.2	60

detailed chemical fractionation of soil samples from the lower Fraser Valley. Various extractants were used which resulted in values for theoretical components such as water soluble, exchangeable and active manganese. Values were similar to other studies but it was noted that total manganese was generally lower than found by Baker (1950) for soils from similar areas. Ultrasonic dispersion was shown to increase recovery by all extractants. Relationships between manganese distribution and factors including type of parent material, pH, organic matter content and cation exchange capacity were evaluated but were not found to be particularly strong. However, the sample set was not large, possibly limiting the determination of such relationships.

Ali (1973) examined the possibility of using hydroxylamine hydrochloride as an extractant for quantifying the "easily reducible" form of manganese, but the amount of data was too limited to conclude the validity of this approach. An additional study applied a wider range of extractants such as sodium pyrophosphate, acid ammonium oxalate, disodium EDTA, hydroxylamine hydrochloride and hydroquinone to gain a better understanding of manganese in soil formation processes (Ali 1975). Sample pretreatment, especially freezing and moist storage, increased manganese extraction. Contrary to the observation of Safo (1970), total manganese of the samples used by Ali (1975) were higher than those reported previously. Lavkulich, Bhoojehur and Rowles (1971) reported relatively high manganese in a pan of a west coast soil profile, showing that manganese was influenced by soil forming processes. Webber (1976) showed that manganese accounted for a considerable portion of the cations on the exchange sites of acid soils, which has implications for liming these soils. Manganese values were reported as technical data for representative soils from a soil survey of the lower Fraser Valley (Luttmerding 1981), however, the method of determination (likely an extraction) was not reported. Chae and Lowe (1976), in a tabulation of total manganese data available for parent materials in British Columbia, identified the variability of the "inherent" manganese in soils. Seven soils from British Columbia (all from the coastal area) were included in a study that examined the general manganese status of Canadian soils in relation to types of deposits and relationships with other measurements (McKeague, Desjardin and Wolynetz 1979, McKeague and Wolynetz 1980). The British Columbia soils were considered to represent the Cordilleran region, but since there were so few samples from this complex region in comparison to other regions, relationships specific to this area were tenuous.

Several studies have examined manganese in soil samples with an environmental rather than agricultural (deficiency or toxicity) or genetic (formation) concern. Warren (1975) included total analyses in a study on the concern for industrial contamination. The data was too limited and variable to be particularly useful. Schreier (1987) and Schreier, Omueti and Lavkulich (1987) showed that serpentine sediments of the Sumas River basin could contribute to manganese in streamwater due to its presence in the asbestos fibres. This many have implications to agricultural activities on these deposits. Wolterson (1989) found that the relatively high background of total (1798-857 ppm) and Mehlich III extractable (44-2 ppm) manganese in Abbotsford and Marble Hill soil profiles and variability within the raspberry fields sampled did not allow distinguishing the effects of manure and inorganic fertilizer histories on manganese accumulations. Only a total of four fields (one for each soil type) were sampled, limiting the conclusions that could be made.

Research under south coastal British Columbia conditions has shown that both deficient and toxic soil conditions exist. The research that has been done shows that these situations occur in a complex way since crop, soil and weather conditions each influence the results and also interact with each other. Although soil types differ considerably in their manganese content, the pH can have a profound influence on availability. Other micronutrients can influence manganese availability directly or indirectly. Crops differ considerably in their manganese requirement and/or their ability to extract soil manganese. Crop response to soil manganese varies from year to year, which may be an effect of weather conditions on the crop or on soil manganese availability. Research on the development of soil or plant tissue analyses for diagnostic or recommendation purposes have not been very successful. Different soil extraction techniques may be required to predict deficiencies vs toxicities. Management practices, particularly liming and others that may also affect soil pH, will need to be considered in determining manganese requirements for crop production. There has been very little data generated for the determination of optimum methods (rate, time, form, placement, etc.) of manganese applications for deficient situations. The method of application will probably have to vary for different crops. A sustained and focused research program will be required to develop methods for estimating manganese availability and deriving methods for its management.

INTERIOR - HORTICULTURE

The possibility of manganese deficiency in fruit trees in the Okanagan was studied as early as the 1930's when McLarty (1936) included manganese borate as a treatment for drought spot and corky core of apple. This physiological problem was subsequently identified as a boron rather than manganese deficiency. But it was about twenty years later that manganese deficiency severe enough to result in visual foliage symptoms in peach, apple and apricot was documented (Woodbridge and McLarty 1951). A foliar spray with manganese resulted in relatively quick recovery of peach trees. The manganese concentration for normal leaves of plants averaged 41 ppm, whereas affected leaves averaged 9 ppm. Corresponding manganese concentrations for apple were 87 and 11 ppm for normal and visually deficient leaves, respectively. This early study did not report any soil analyses. A subsequent study (Woodbridge and McLarty 1953) reported pH of surface (0-30 cm) soils of orchards ranging from 7.2 to 8.0, and the severity of the observed symptoms tended to be greater as the pH increased. Mason, Gardiner and Sanderson (1972) found that a dimethyldithiocarbamate spray was effective in increasing leaf manganese concentration, however, their report was only intended to study the potential of this spray to supply manganese to the tree since neither yield effects nor the actual need manganese (nor other nutrients) were considered.

Twenty to twenty-five years after research on manganese deficiency was published, a new manganese problem surfaced. There was an increasing concern for inadequate calcium content in "Spartan" apples for storage problems (Mason and McDougald 1974). In that solution culture study, analyses showed that leaf manganese was decreased by increased solution calcium concentration, although the manganese concentration of flesh of the fruit was not affected. Subsequent work showed that visual symptoms (internal bark necrosis) of excessive manganese in Delicious apple orchards were generally associated with soil pH below 5.6 and leaf manganese concentrations above 120 ppm (Fisher, Eaton and Porritt 1977). The Delicious apple cultivar was observed to be more susceptible to excessive manganese accumulation than Golden Delicious and McIntosh cultivars (Hogue et al 1983). The change in research emphasis from manganese deficiency to toxicity was related to the recognition of enhanced soil acidification in the apple orchards due to activities associated with intensive tree fruit production such as irrigation and especially nitrogen fertilizer application. Acidification of apple orchard soils resulted in sharp increases in 0.02 M calcium chloride extractable manganese (Ross, Hoyt and Neilsen 1985). Likewise, exchangeable manganese in soils as determined by neutral normal ammonium acetate extraction was observed to increase logarithmically as soil pH decreased ($r = -0.76$) and was positively related ($r = 0.56$) to apple leaf manganese (Neilsen, Hoyt and Lau 1982). Extractable soil manganese showed the largest increase in most orchard soils as soil pH (0.01 M $CaCl_2$) decreased below 5. Similar strong negative correlations (r ranging from -0.45 to -0.81) were measured in six different orchards between soil pH (0.01 M $CaCl_2$) and 0.02 M extractable soil manganese, regardless of a range of rootstocks among orchards (Hoyt and Neilsen 1985). Furthermore, in 4 of the 6 orchards, tree size of "Delicious", "Tydeman" and "Rome Beauty" apple cultivars correlated positively with soil pH implying a growth inhibition due to soil acidification, which included increased manganese solubility. In a survey of a large number of "Delicious" apple orchards, Hoyt (1988) observed a general relationship between internal bark necrosis and leaf manganese concentration. Average leaf manganese concentrations increased from 67 ppm in plants showing no symptoms to 306 ppm in plants showing severe symptoms. Tree age seemed to be an important factor, with younger trees showing symptoms more readily. In contrast, rootstock did not seem to be important. Internal bark necrosis showed "little or no relationship with soil pH, 0.02 M calcium chloride manganese or exchangeable bases, even though (symptoms) differed widely (among) orchards". This difference from previous research may suggest that other factors may affect the relationship of various soils and plant types to plant manganese including, for example, factors affecting the transfer of manganese within the plant from root to shoot. Research on the appropriate method, form and rates of lime application to correct pH decline (Hoyt and Drought 1990) has used decreased leaf manganese concentration as a sensitive indication of success of liming (Neilsen, Hogue and Drought 1981). Sweet cherry is generally known to accumulate higher manganese concentration in leaves than "Delicious" apple trees, which are sensitive to the internal bark necrosis manganese disorder. However, there has been little research to determine whether manganese toxicity is a problem in cherries. Root nutrient inflows of manganese for wild cherry (Prunus avium L.) decreased as pH in 0.01 M $CaCl_2$ increased from <4 to about 5 (Neilsen, Neilsen and Atkinson 1990). Phosphorus decreased manganese inflow rates at the lower soil pH but the increased root length, apparently stimulated by phosphorus, resulted in greater tree accumulation of manganese. Increased leaf manganese concentration in apples has also been an observed consequence of applying monoammonium phosphate or a manganese containing fungicide in the planting hole (Neilsen and Yorston 1991). Effects of these treatments decline after the first year and are only likely to be a problem for apple varieties such as "Bisbee" Delicious, which are particularly sensitive to manganese toxicity.

Field research has shown that both manganese deficiencies and toxicities occur in Okanagan orchards. Foliar sprays are recommended for treatment of manganese deficiency (B.C. Min. of Agric. and Fisheries 1989). Leaf tissue manganese concentration of trees has been used to differentiate deficient (below 25 ppm) and toxic (above 60 ppm) Delicious apple trees in a research study (Neilsen, D. et al 1990). Critical manganese concentrations of 25 ppm dry weight for apple, pear, peach and apricot, and 20 ppm for cherry and prune have been set for leaves sampled from the mid-terminal position of the branch (B.C. Min. of Agric. and Fisheries 1989). Leaf washing requirements have been examined (Ashby 1969a), and it appears that various strains of a specific crop such as Delicious apple (Jonker 1986) differ little in their manganese requirement as shown by leaf manganese concentrations under similar conditions. Petiole analysis benchmarks for adequate nutrition for grapes (18-100 ppm for V. labrusca and hybrids and 30-150 ppm for V. vinifera) are being used (B.C. Min. Agric. and Food 1985a), based on survey (Parsons and Eaton 1980), unpublished and general literature data. More recently work has been focused on the possible use of soil testing. Neilsen, D. et al (1990) found that subsurface (15-30 cm) appeared to be more useful than surface (0-15 cm) samples for distinguishing manganese status of soils, and that the same extractant may not be appropriate for distinguishing both deficient and toxic situations. For soils with pH > 6.5, extraction with 0.25 magnesium chloride or DTPA gave more consistent correlations with apple leaf concentrations, whereas for soils of pH < 6.5, 1.0 M ammonium acetate, 0.25 M magnesium chloride or 0.02 M calcium chloride gave better relationships with leaf manganese. The various significant correlation coefficients for extracts of 15-30 cm depth soil manganese to leaf manganese concentration ranged from 0.53 to 0.70. The moderately low but significant correlations, higher correlation with subsurface than surface samples, and the need to use a different extractant at a different pH shows that several factors may need to be included in developing a manganese soil test suitable for orchard crops.

The recognition that manganese can influence tree fruit production has resulted in that element being considered when interpreting other studies such as on other nutrients or various manganese practices. Removal of fruit resulted in a subsequent decrease in leaf manganese (Jentsch and Eaton 1982). This decrease was attributed to fruit acting as a "strong metabolic sink". Manganese was also examined in studies focusing on other nutrients or management factors. From 4 to 43% of total soil zinc was found to be associated with manganese oxides (Neilsen, D., Hoyt and MacKenzie 1987). Increasing the rate of nitrogen fertilizer application (Neilsen, Meheriuk and Hogue 1984), the frequency of irrigation (Neilsen and Stevenson 1986), and the temperature of the root in a nutrient culture system (Hogue and Neilsen 1986) increased the manganese concentration of apple leaves, whereas vegetation control of the orchard floor by various types of cultivation or non-cultivation, or use of black plastic mulching and excessive annual applications of various herbicides did not affect apple leaf manganese concentration (Neilsen and Hogue 1985, Neilsen, Hogue and Drought 1986, Hogue and Neilsen 1988). Municipal wastewater used for irrigation resulted in increased manganese uptake by vegetable crops, apples, sweet cherry or grapes relative to these crops irrigated with well-water, despite a low manganese content in the wastewater (Neilsen et al 1989a, 1989b, Neilsen, Stevenson and Fitzpatrick 1989, Neilsen et al 1991).

Studies on interior soils used for horticultural production with a view to examining soil processes, etc. have been conducted much less frequently than for coastal soils. Many of these studies are fairly limited, with specific information, and are only generally useful (Vernon 1951, Kelley and

Holland 1961, Ali 1973, Warren 1975, Chae and Lowe 1976). The early study by Baker (1950) included only four samples from horticultural areas of the interior and these were from uncultivated sites. The pH of the surface samples ranged from 7.3 to 7.6 and "available" manganese (22-90 ppm) accounted for 1.8 to 5.2% of total manganese measured. This limited information is more useful for plantings on newly cultivated soils than for those that have been weathered and acidified by intensive tree fruit production.

In summary, early research identified manganese deficiency for most tree fruit crops in interior British Columbia, which resulted in the development of leaf diagnostic standards and recommendations for ameliorative manganese sprays. Sporadic reports of manganese deficiency still occur, particularly during cool springs on soils of high pH or salinity, or with restricted rooting depths as a result of a high water table. Manganese toxicity subsequently became apparent as severe stunting of and internal bark necrosis ("trunk blistering") on trees especially on "Delicious" apple trees on soils which have acidified. Accelerated soil acidification has been strongly associated with nitrogen or phosphorus fertilizer application together with irrigation. A marked result of soil pH decline has been increased solubility of soil manganese. This has increased research on manganese "detoxification" of soils by liming, and concern for new orchard production practices and soil characteristics that accelerate acidification. Practices such as applying nitrogen fertilizer via irrigation water (fertigation) needs to be assessed since there would be increased potential for acidification. The acidification potential would be further intensified by trickle fertigation when the water and fertilizer is concentrated in a smaller portion of the root zone. This site-specific water application makes it more difficult to develop diagnostic soil tests or to elucidate basic soil and plant manganese relationships. More knowledge is required to characterize the manganese status of soil in horticultural areas of the interior where both manganese deficiency and toxicity have been shown to occur.

INTERIOR - FORAGE

The status of manganese in the extensively farmed interior of British Columbia has only been studied since the early 1960s, and these studies frequently included a range of micronutrients rather than focusing solely on manganese. Miltimore et al (1964) included manganese in a study of potential copper deficiency in cattle pastured on "ground-water" soils. They concluded, from chemical analyses of plant material, that manganese was adequate and did not contribute to the specific problem identified. Mason (1964) reported preliminary results showing that alfalfa yield at Armstrong was increased by several nutrients including manganese, but a final outcome of this study was not reported in a research publication. Pringle and Van Ryswyk (1965) did not observe a response to manganese in a study of water sedge grown on peats from Williams Lake or Miocene in a growth room study. Phosphorus appeared to be the most limiting nutrient in that study. The micronutrient status was not examined very thoroughly, with only application of several elements in fritted form. The effect of alternate sources or responses of other crops, etc. was not reported. Similarly, Freyman and Van Ryswyk (1969) did not observe a response to a Long Ashton solution containing multiple micronutrients by pinegrass grown on Grey Wooded soils, but this was not examined in more detail as, for example, treatments of individual micronutrients, at various rates and forms. Van Ryswyk, Hubbard and Miltimore (1973) found that hay from sedges (exact location not documented) contained 108-149 ppm Mn after growth in an organic soil in interior British Columbia. These concentrations were considerably higher than for an alfalfa hay reference sample which ranged from 26-32 ppm Mn. The alfalfa hay was assumed to have insufficient manganese for livestock feed. Fertilization of the sedge with nitrogen, phosphorus and potassium did not statistically affect the manganese concentration. A single nitrogen application in 1958 to beardless wheatgrass did not affect manganese concentration (59 to 66 ppm) when sampled in 1967, but had slightly increased manganese concentration (42 to 47 ppm) by 1969 (Mason and Miltimore 1972). The manganese content of meadow foxtail declined from 177 to 124, 250 to 166 and 320 to 217 ppm for cuts 1, 2 and 3, respectively, as the rate of nitrogen application increased from 0 to 224 kg N/ha (Van Adrichem and Tingle 1975). This was inversely related to the 3.5- to 7.2-fold increases in yield, suggesting that the decreased manganese concentration was due to a dilution effect. This study also showed that this soil was well supplied with manganese and that the manganese concentration varied with season. Manganese concentration of grass samples reported in the Okanagan, in a study that focused on copper and selenium, were relatively uniform and ranged from 40 to 51 ppm including samples from upland and "groundwater" sites (Miltimore et al 1973). In a very general and limited (seven sites) comparison near Shuswap Lake, Ruckle (1977) found that the manganese content of wet meadow plants tended to be higher than soil manganese but soil and plant manganese were not generally correlated. Although manganese was not the primary element in a study of the nutrition of forages in the Vanderhoof-Fort Fraser area, some data was presented on DTPA, EDTA and hydrochloric acid (0.1 N) extractable manganese from 41 mineral soils and comparisons were made with extractable copper and zinc (Lowe and Milne 1979). Extractable manganese from the 41 soils averaged 76 ppm with EDTA and 70 ppm with HCl and was considerably higher than with DTPA (14 ppm). The amount of manganese extracted by all of the extractants, and particularly by EDTA and HCl, were considerably greater than the amounts of copper or zinc extracted. The amounts of manganese extracted by DTPA from soils of different textures, ranging from clays to loamy sands were quite similar (average of 14 to 22 ppm for the various textural groups). Manganese was ruled out by plant analysis as a cause of the visible nutrient deficiency in corn grown on Fleet series soil at Kamloops Research Station (Broersma and Van Ryswyk 1979).

Miltimore (1967) used analyses of interior feed samples to estimate the general status of a number of nutrients for cattle production purposes. That study found that hay samples contained a wide range of manganese concentrations with 32% below the 40 ppm considered to be the minimum required for cattle, and 22% above 100 ppm which could potentially interfere with the utilization of other nutrients, notably copper. It was concluded that manganese deficiency, at least for forage quality, was "confined to small geographic areas if they occur". There has been a subsequent series of similar studies using feed analysis to assess the nutrient status of cattle production areas in the interior. A survey of a wider range of feeds in the province showed that 40% of the samples tested were below the recommended minimum of 40 ppm (Miltimore, Mason and Ashby 1970). One-quarter of the grass samples contained more than 151 ppm Mn. Since hays and grains were fairly high in manganese, a mineral supplement including manganese for ruminants may not always be required and would depend on the type and pattern of feeds used. In a more detailed study of cereals and their cultivars, differences were noted (Tingley and Dawley 1972). It was concluded that "all of the material grown at Vanderhoof and some of the barley cultivars at the other locations", if used as silage, were below the 40 ppm Mn concentration assumed to be required for livestock production. Several research (Pringle, Dawley and Miltimore 1973, Miltimore, Kalnin and Clapp 1978) and technical (B.C. Min. of Agric. 1978, Kline 1981, Anonymous 1984a, 1984c, 1984d, Soder 1984) publications report manganese analyses of feed materials but provide little additional information beyond showing that concentrations in this area vary considerably, likely depending on many factors. Bomke and Lowe (1991) found that the manganese concentration in barley forage grown in pots on a Prince George area clay soil, treated with deep-pit manure to rates up to 40 t/ha, were significantly lower than in the control treatment. This decrease appeared to be due to a dilution as a result of the large crop dry matter response to the manure. Uptake of manganese by the manure treated crop was greater than in the control. The manure had contained 271 ppm manganese.

A study by Kynaston (1953), which showed that micronutrients can influence the germination of various forages and cereals, may have some relevance to the interior of British Columbia. Practical application of the finding would depend on a number of climatic, management and economic factors, and more research would need to be done.

Considerably less manganese work has been reported on soils for the northern interior of British Columbia than that reported for the Okanagan and south coast. Baker (1950) included five samples from the central interior (Nechako Plateau) and three from south eastern British Columbia in a general manganese study of the province. The uncultivated soils from these areas ranged considerably in total manganese (144 to 4936 ppm), possibly reflecting the wide diversity of soils tested. These samples had pHs ranging from 4.4 to 7.6. "Available" manganese was reported only for the five Nechako Plateau samples and ranged from 22 to 324 ppm, accounting for 2 to 12% of the total manganese. The studies by Vernon (1951) and Ali (1973) and a review by Chae and Lowe (1976) may also be relevant but provide limited data for the area concerned. Soil surveys report some analytical results on manganese (Runka 1972, Lord and Green 1986), but these are difficult to interpret since the methods used are not always well documented. Farstad and Laird (1954) concluded that soils in the Quesnel, Nechako, Francois Lake and Bulkley-Terrace areas have adequate manganese, but this conclusion was probably based on the limited number of samples analyzed by Baker (1950). The study by Yee and Broersma (1988) included interior soil samples but did not specifically focus on manganese. Chuah (1990) concluded that manganese is not lacking in soils of central and northern British Columbia but this was based on soil test analysis, using a DTPA extractant, which has not been thoroughly evaluated for these areas.

A few studies have been completed for interior soils where there was a concern for excessive manganese. Localized areas were identified where the manganese content was high but these were due to contamination from industrial activities (Warren 1975, Natsukoshi 1979, Haak 1980). There may also be specific situations of excessive manganese for crop production due to the acidity of the soil (Hoyt and Nyborg 1971b, 1972, Hoyt and Webber 1974, Webber 1976).

The limited local research data for interior soils used for extensive agricultural production indicates that available soil manganese varies from quantities that are sufficiently low to result in a deficiency with respect to animal feed quality and also sufficiently high to result in plant toxicity. These problems appear to be quite variable and scattered in the very large area in question. The variability of available manganese appears to be related to many factors, but the diversity of soil types (parent materials and soil genesis) and pH may be important factors. Crop yield responses to manganese fertilizer applications have been variable and usually minimal, but then these studies have usually been conducted as part of other treatments and not specifically on manganese. Considerable field research would be required to define the actual manganese status of the soils of the area and would probably have to include research on the basic soil-plant factors affecting manganese accumulation. The most immediate concern is the effect on animal production. Forage analyses have been scattered and now are dated, limiting conclusions on which firm recommendations can be based. Since livestock tend to feed on forage from a very wide area (by grazing or by being supplied hay or grain from another area), it is difficult to be sure that there is adequate and uniform manganese intake over the life of the animal. Since crop yield responses to manganese applications have tended to be minimal, it may be more economical to supplement it directly to the animals. However, the method for determining whether the animals are receiving adequate, but not excessive, manganese would have to be simple and effective.

PEACE RIVER

There appears to be relatively little information that shows whether or not there is potential for manganese deficiency in the Peace River area of British Columbia. Miltimore, Mason and Ashby (1970) examined manganese concentrations of ruminant feeds from the entire province but did not distinguish a manganese deficiency problem for the Peace River area. Several reports indicate manganese concentrations in forage for the Peace Rive area but do not interpret the values (B.C. Min. of Agric. 1978, Anonymous 1984e, Soder 1984). The values suggested sufficient amounts of manganese, but that there was considerable variation in the concentrations. More work has been reported on the potential for manganese toxicity in relation to acid soils that occur in this region. Most of this work included data for various extractions of manganese (Nyborg 1970, Hoyt and Nyborg 1971b, 1972, Elliott et al 1973, Hoyt and Webber 1974, Webber 1976, Nyborg and Hoyt 1978). Although several extracts were examined and variable relationships to plant manganese were observed, it appears that an extract containing a low concentration of calcium chloride (i.e. soil solution manganese) provided a good indication of toxic concentrations in these soils. Part of the problem of definitively determining manganese toxicity in these soils was that manganese is frequently closely related to excessive amounts of aluminum. Several theses have been conducted that include manganese for the Peace River or related conditions. These were studies of basic usefulness and tend to be dated (White 1940, Gregory 1947, Kynaston 1953). Baker (1950) found that total manganese in eleven surface samples of uncultivated soils from this area ranged from 66 to

1150 ppm and between 0.6 and 29% (7 to 36 ppm) could be extracted as "available" manganese. These values were interpreted by Farstad et al (1965) to suggest that Peace River soils "have adequate amounts of both total and available" manganese for crop production. The extraction studies of Vernon (1951), Ali (1973) and Yee and Broersma (1988) and total analyses reported by Warren (1975) and Chae and Lowe (1976) provide little information on which to base practical conclusions. Should liming of soils in the Peace River area become more prevalent, increased attention to the possibility of lime induced manganese deficiency, besides manganese toxicity, will be necessary.

SUMMARY

Situations of manganese deficiency and/or toxicity occur throughout the province. Soil pH is the most important factor influencing availability. Plants differ considerably in their response to low as well as excessive amounts of manganese in the soil. In the south coast, with the wide variety of crops grown and variable soil pH due to gradual acidification and regular liming, the situation is relatively complex. In the Okanagan, manganese deficiency was quite widespread at one time, but now that the soils have become acidified from intensive management practices, particularly fertilizer application and irrigation, manganese toxicity is becoming more prevalent. Manganese toxicity, usually related to low pH soils, also occurs in the Peace River area and the interior. Feed analysis suggests that plants growing in the interior can frequently be marginal or deficient in manganese for livestock, but only one instance of plant yield response to manganese application has been documented. However, this type of study has not been frequent nor thorough. Unless significant yield responses by forages in the interior can be shown, supplementation of livestock feeds with manganese may be more efficient than the use of fertilizer on the plants. Soil analysis research has been conducted and some extracts show promise for predicting deficient or toxic situations, but the work is insufficient to support a soil test system. It may be necessary to use two different extractants, one for identifying deficiency and another identifying toxicity. Any soil test system that will be proposed for identifying low manganese in acid soils will have to consider the potential for lime-induced manganese deficiency.

IRON

SOUTH COAST

There was early research on the possibility of iron deficiency in the south coast, when a production problem of raspberries was thought to be related to nutrition (Harris and Woods 1935, Harris 1936, 1937, 1940, Atkinson and Wright 1942). Soil analyses involving examination of elements in "soil solution" or "displaced soil solution" were a large part of the studies. Although there were analytical limitations during that time, the studies concluded that iron was not a nutritional problem. About that time, Hicks (1941) examined the effect of various elements on the growth of actinomycetes selected from an upland glacial soil of the coast and found that iron had the largest effect. This work does not appear to have been followed up in British Columbia and hence the significance of the results to crop production cannot be evaluated. Iron was one of several nutrients analyzed in a blueberry nutrition study in the Richmond area (Herath and Eaton 1968). Leaf iron was one of six elements that responded to water table treatments. A positive correlation between leaf calcium and iron concentrations was recorded, although no relationship between iron and vegetative or reproductive growth was found. From the dearth of comment on the iron results in the discussion, it appears that iron was not considered an important factor in the responses. Iron was considered once again in the general nutrition of raspberries in a 1971 report (John, Carne and Eaton 1971). That survey study included both soil and leaf analyses and the only significant correlation documented for iron analyses was that between leaf iron and soil extractable magnesium. The correlation (r = -0.22) was negative and rather weak. Conclusions on the general nutrient status of raspberries was limited by the lack of critical leaf nutrient concentrations. As a result of this lack of information, a series of studies were conducted on both raspberries (John and Daubeny 1972, John, Daubeny and Chuah 1976) and strawberries (John, Daubeny and McElroy 1975, John et al 1976) to examine factors (such as time of sampling, type of tissue, genotype) which may influence leaf element concentrations. Iron was included as one of many nutrient elements, but the information was not sufficient to derive a suitable analysis method or diagnostic standards for iron. Also, there have been no follow-up studies on British Columbia raspberries. Maas (1975) concluded that micronutrients including iron were not limiting in Vancouver Island soil but the study, which was conducted in a growth chamber using sunflower as a test crop, was not thorough in its assessment of nutrient requirements. Nutrition-oriented studies of forest trees have also considered iron (Carter, Otchere-Boateng and Klinka 1984, Davis 1987) but the limited results did not show an evident iron problem.

John, Case and Van Laerhoven (1972) included a soil extraction for iron in a study on the effect of lime applications on alfalfa growth. Extractable iron, in this case the North Carolina extract consisting of a mixture of hydrochloric and sulphuric acids, was found to be significantly but negatively and weakly correlated (r = -0.28) with alfalfa yield. The negative correlation was due to the increased growth of alfalfa as the soil pH was increased by the lime applications (Table 5). In general, extractable iron increased as soil pH decreased. Ali (1975) included iron in a soil extraction study that focused on manganese. Hydroxylamine hydrochloride was not as effective at extracting iron as it was for extracting manganese, but pyrophosphate, EDTA and oxalate extractants did extract significant quantities of iron. Extraction of the soil with DTPA was able to detect the influence of sewage sludge applications on iron (Yole 1980). More recently, Yee and Broersma (1988) found that DTPA-TEA, Mehlich III (a combination of acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and EDTA) and acetic acid-DTPA extractions of iron gave comparable regressions with plant iron concentrations. The coefficients of determination were low (R^2 = 0.16-0.37) but significant at P>0.01 level. That pot study involved soils from throughout British Columbia with a few from Alberta. However, iron was not a treatment and no yield responses to iron applications were assessed. Kowalenko (1991), using a $CaCl_2$ extract containing DTPA and TEA at pH 7.3, found that soil extractable iron did not change over the winter in a three year study on six fields on a Monroe series soil. The extractable iron in the fields differed and ranged from 69 to 139 ppm but were not related to their management. Four of the fields grew grass and two grew forage corn. The

Table 5 Comparison of total above ground alfalfa yield with pH and extractable (North Carolina method using 0.05 N HCl in 0.025 N H_2SO_4) iron after plant growth in Fraser Valley soils limed to specific base saturations (adapted from John, Case and Van Laerhoven 1972)

Soil	Liming treatment	Yield (g/pot)	pH	Iron (ppm)
Ladner	No lime (40% sat.)	5.7	4.8	182
	To 70% base sat.	19.9	5.5	98
	To 100% base sat.	22.7	6.3	71
Hazelwood	No lime (30% sat.)	8.3	4.8	49
	To 40% base sat.	14.1	5.1	34
	To 70% base sat.	20.2	6.0	18
	To 100% base sat.	24.7	6.8	12
Monroe	No lime (63% sat.)	13.7	5.2	74
	To 70% base sat.	22.9	5.5	68
	To 100% base sat.	25.2	6.6	53
Fairfield	No lime (46% sat.)	8.6	5.1	65
	To 70% base sat.	16.7	5.9	66
	To 100% base sat.	23.0	7.0	27
Whatcom	No lime (20% sat.)	9.7	5.4	17
	To 40% base sat.	12.1	5.8	11
	To 70% base sat.	19.5	6.3	7
	To 100% base sat.	18.8	6.8	5
Marble Hill	No lime (24% sat.)	7.4	5.6	53
	To 40% base sat.	12.9	5.9	43
	To 70% base sat.	10.6	6.6	31
	To 100% base sat.	14.1	7.1	20
Annis Muck	No lime (22% sat.)	17.8	4.4	229
	To 40% base sat.	21.7	5.0	70
	To 70% base sat.	23.8	5.7	27
	To 100% base sat.	23.0	6.1	13

iron content of forage materials also provides limited information on the iron status of crops in this area. Miltimore, Mason and Ashby (1970) indicated that British Columbia forages in general tend to be well above the 30 ppm that has been suggested as a minimum requirement by livestock. Subsequent Fraser Valley studies (Peterson and Waldern 1977, Cathcart, Shelford and Peterson 1980) tend to support the conclusion that iron is not limiting in forage materials in south coastal British Columbia, however, the latter study suggested that some of the higher iron concentrations in feeds may be due to soil contamination of the samples. With the concern for soil contamination, reported iron values of submitted feeds (Anonymous 1984b, 1984f, Soder 1984,) should be interpreted with caution.

Iron analyses have been included in a number of plant-oriented studies and provide some useful general information, but have not directly considered iron deficiency or sufficiency for crop production. The studies relate to effects of management practices, and applications of various amendments that can contain iron. Kynaston (1953) showed that micronutrients, but not iron specifically, may have varying effects on the germination of forage seeds depending on the circumstances involved. Maurer and John (1971) showed that fumigation of Lumbum muck soil increased the iron concentration of carrot foliage but did not affect that of the roots. Amendment of soil with liming materials were shown to influence red clover iron content when the element was added as an incidental part of the amendment, such as in electric furnace slag (Beaton, Speer and Harapiak 1968), or by the amendment affecting the availability of iron already present in the soil (John et al 1972). Amendment of soil or growth media with manganese (Eaton and John 1971, Kowalenko 1989), lead (John and Van Laerhoven 1972), cadmium (John 1976) and boron (John, Chuah and Van Laerhoven 1977) have been shown to influence the iron content of various crops in a variety of ways. Poultry manure (Bomke and Lavkulich 1975, Safo 1978) and sewage sludge (John and Van Laerhoven 1976, Yole 1980) have shown that iron uptake by crops was affected by both the iron added with the amendment and also by the organic constituents of the soil.

Iron has also been considered in the genetic classification of soils in Canada, and soil survey reports for the south coast of British Columbia have included iron analyses (Kelley and Spilsbury 1939, Day, Farsted and Laird 1959, Luttmerding 1981). The values reported are extractions that relate to soil genetic processes (Lavkulich, Bhoojedhur and Rowles 1971, Sanborn and Lavkulich 1989) and there is no reason to expect a relationship to crop production. Keng and Kusaka (1988) observed accumulations of ferric oxide (iron ochre) in drain tiles and on plant roots in the drain tiles of the Fraser Valley. Although the concern with iron ochre is eventual plugging of the drain tiles, it does show that there can be an abundance of iron in certain soils. Cross (1975) found low amounts of iron associated with the organic matter in the profiles of two mineralized soils. A study which included total iron analysis of soils from throughout Canada (McKeague, Desjardin and Wolynetz 1979, McKeague and Wolynetz 1980) provided some very general comparative data but, since only seven soils were from British Columbia (six from Vancouver Island and one from the Fraser Valley), firm conclusions on the distinctiveness of iron content of these soils cannot be made. Asbestos-rich serpentinitic sediments which occur in the Sumas River basin of south coastal British Columbia, have been shown to contain some but not an abundant amount of iron (Schreier 1987, Schreier, Omueti and Lavkulich 1987). This information may have some implications to the iron status of soils influenced by sediments from this river system but more research would be required.

Iron has been examined in soils in relation to its effect on other elements in the soil using south coastal soil samples. Clark (1964) showed that iron and aluminum can influence the amount of hydrogen that is adsorbed in soils since these cations would compete for exchange sites. This process would be particularly important in soils of low pH. Levesque (1974) found that selenium distributed in soils was closely associated with oxalate extractable iron. This relationship was derived from a study of soils from throughout Canada, but of the 54 profiles only 5 were from British Columbia. Unfortunately, the location of the soils was not given and the British Columbia soils were only identified as podzols, brunisols and a gleysol. Gu (1986) found boron adsorption by organic constituents occurred in soils with high amounts of extractable iron and aluminum.

Iron has also been considered in relation to its effect on analytical methods and investigated for British Columbia conditions using south coastal soils. The methods involved copper (Clark 1950) and boron (John, Chuah and Neufeld 1975, Kowalenko and Lavkulich 1976) analyses. This information is useful for interpretation of data but does not directly contribute to an evaluation of the iron status of south coastal soils.

There is little evidence of iron deficiency for crop production in south coastal British Columbia from the relatively little research that has been done directly on this aspect. Crop response research has been confined to relatively few crops, and has not been thorough with respect to consideration of the influence of soil pH. Iron in animal feeds grown in the area appear, from chemical analysis, to be adequate but soil contamination probably contributed to these values. A few studies have examined extraction procedures for measuring plant available iron in soils, but the results are inadequate to derive recommendation procedures. Soil iron analyses have been done in relation to soil genesis and classification, but these are of limited agricultural usefulness.

INTERIOR - HORTICULTURE

General recommendations had been developed for iron application, and iron leaf concentration standards (>45 ppm dry weight for all cultivars) were in use for fruit trees (B.C. Min. of Agric. and Food 1989) and grapes (B.C. Min. of Agric. and Food 1985a), there is a dearth of local research data published by which to justify these recommendations. Much of the information has been developed in the process of correcting obvious iron chlorosis symptoms, which have been observed from time to time on most fruit tree cultivars. Symptoms (overall chlorosis of young leaves) usually occur on high pH sites, especially where seepage has resulted in the accumulation of salts in the soil. Peach, pear and apricot are more susceptible to the development of symptoms than apple. Corrective treatments have been based upon the temporary greening of foliage after sprays of chelated iron. It has been difficult, in practice, to use leaf iron concentrations to identify inadequate iron nutrition due to a lack of correlation between total tissue iron concentration (as opposed to "active" iron) and chlorosis symptoms.

The earliest report of iron treatment of fruit trees in the interior appears to be an injection study by McLarty (1936). Iron was one of several nutrients applied to trees with drought spot and corky core symptoms but it did not influence the fruit disorder. Studies on contamination during leaf tissue sampling (Ashby 1969a), on dimethylcarbamate sprays as a form of nutrient application (Mason, Gardiner and Sanderson 1972) and on the effect of strains of apple trees on leaf iron concentrations (Jonker 1986) provide useful information to evaluate iron spray treatments and iron accumulation, but do not establish the significance of iron deficiency in horticultural crops in the interior. It is also difficult to extrapolate research conducted in pots with an annual crop to fruit tree or grape production in the field.

Research on iron in relation to soils used for horticultural production in the interior of the province is also limited. Soil survey reports have included iron analysis values (Kelley and Spilsbury 1949, Kelley and Sprout 1956, Kelley and Holland 1961, Sprout and Kelley 1964), but the values were extractable iron which were intended to examine soil genesis and not crop requirements. In the survey of the Okanagan and Similkameen valleys, Kelley and Spilsbury (1949) suggested that the iron content of these soils was comparatively high. This conclusion was based on limited information and soils analyzed many years previously. Iron has been examined in relation to other elements such as selenium (Levesque 1974), zinc (Neilsen, D., Hoyt and MacKenzie 1986), and also in relation to acidification (Ross, Hoyt and Neilsen 1985). This is generally useful information but again does not address the issue of evaluating the relative availability of iron. The study by Ross, Hoyt and Neilsen (1985) showed that acidification, which has been enhanced by irrigation and fertilization of interior soils, increased the solubility of iron. This would likely mean that iron is be more available to plants upon acidification, but that liming would reverse the situation. General studies on the effects of liming Okanagan soils showed that the iron content of the flesh of apple fruit was reduced (Mason and MacDougald 1974). On the other hand, leaf iron content of apple trees did not respond to changes in soil pH (Neilsen, Hoyt and Lau 1982). Leaf iron was also unaffected by various orchard soil management treatments (Neilsen and Hogue 1985) or root temperature or varying solution cation ratios (Hogue and Neilsen 1986). Neilsen et al (1989a) showed that Osoyoos sewage effluent contained measurable iron, which could be a source of that nutrient to crops, but plant iron response was not examined in that study.

Although there has been little systematic research on the studies of soil or plant iron for production of horticultural crops in interior British Columbia, obvious iron chlorosis symptoms have been observed from time to time on most fruit tree and grape cultivars. Particular iron deficiency problems have been observed in the Similkameen Valley and associated with high pH soils, or those with free lime, and with drainage properties of the soil. It is for this reason that additional research is needed to develop methods for increasing soil iron availability (e.g. acidification), in order to ameliorate iron deficiency symptoms in crops grown on problem soils.

INTERIOR - FORAGE

Mason (1964) published the earliest report found where iron has been applied as a nutrient to a forage in the interior of British Columbia. That preliminary study near Armstrong did not detect a response to iron, although there was a response to several other micronutrients applied. Pringle and Van Ryswyk (1965), working with water sedge, and Freyman and Van Ryswyk (1969), working with pinegrass, did not show yield response to multiple micronutrient applications that included iron. Broersma and Van Ryswyk (1979) concluded, from a comparison of plant iron analyses with critical values reported in the literature, that a nutritional problem with corn near Kamloops was not due to iron. Chuah (1990) concluded, from soil test analyses, that iron appears to be adequate in the central and northern interior, but that more research, such as that by Yee and Broersma (1988), is needed to determine whether the soil extract that was used is suitably diagnostic. Ruckle (1977) found that iron concentration measured in vegetation and soils were generally similar in wet meadows at Celista near the Shuswap Lake, with the concentration higher in the vegetation than in the soil. At one of the seven sites, which was well drained, iron concentrations were reported to be unusually high. Majid (1984) did some exploratory work on the iron nutrition of lodgepole pine and Douglas fir in the interior, but the study did not establish actual iron deficiencies since method development was the main focus of the study. Mason and Miltimore (1972) found that nitrogen applications that increased beardless wheatgrass yield did not influence the iron concentration of the grass.

Although Miltimore (1967) found that 28% of samples analyzed in a survey of the nutritional status of feeds in the interior were less than the concentration (57 ppm) considered inadequate for cattle, many other samples were found to be very high in iron. It was concluded that since there was such a wide range of iron in the feeds that cattle, with access to a wide variety of feeds, would consume adequate iron. Subsequent research studies (Miltimore, Mason and Ashby 1970, Pringle, Dawley and Miltimore 1973, Miltimore et al 1973, Van Ryswyk, Hubbard and Miltimore 1973, Miltimore, Kalnin and Clapp 1978) and documentation from laboratory analyses of submitted samples of animal feeds (Anonymous 1984a, 1984c, 1984d, Soder 1984) also showed that iron concentrations varied considerably and did not appear to be nutritionally limiting.

Iron analyses of soil samples have been reported in many soil survey reports (Kelley and Farstad 1946, Kelley and Spilsbury 1949, Farstad and Laird 1954, Kelley and Sprout 1956, Cotic, Van Barneveld and Sprout 1974, Runka 1972, Lord and Mackintosh 1982, Dawson 1989) but these analyses were oriented toward the genesis and classification of the soils rather than an assessment of the iron supplying capability for crops.

Iron has been included in some pollution oriented studies in the interior, but the problems examined have been at specific locations related to industrial activities (Natsukoshi 1979, Haak 1980).

Although the amount of research directly on iron as a nutrient element has not be very great for the interior of the province used for forage production, the evidence that there is suggests that iron is largely adequate for the extensive type of agriculture in the region.

PEACE RIVER

There has been relatively little research reported concerning the iron status of the Peace River region of British Columbia. Research studies (Miltimore, Mason and Ashby 1970, Pringle, Dawley and Miltimore 1973) and documentation of analyses of samples submitted for laboratory analyses (Anonymous 1984e, Soder 1984) show that feed samples in the Peace River area vary considerably in their iron content, but that iron does not appear to be a nutritional problem for cattle production. A soil survey report of the area (Farstad et al 1965) included iron analyses of representative soils but the analyses were related to genesis and classification. Nyborg and Hoyt (1978) indicated that soluble iron was not related to nitrification in a study of acid soils, but the actual iron values were not reported. The study by Yee and Broersma (1988) provides useful basic information in relation to iron status of soils, but does not provide an assessment of crop response to iron additions.

As for forage production in the interior region of the province, iron does not appear to be limiting for the current type of agriculture in the Peace River, but more research is needed to confirm this conclusion for the wide range of crops grown in this area.

SUMMARY

Research on the status of iron for crop production and animal feed quality in the province is quite limited and in most cases the research on the element has been a part of other considerations. Other than in the Okanagan and Similkameen Valleys, iron does not appear to be limiting both for crop growth or in animal feed. Chlorosis associated with iron deficiency has been observed on tree fruits and grapes in the Okanagan and Similkameen Valleys. These instances have been associated with high pH, free lime or poor drainage. However, little direct and systematic research has been conducted on determining methods for predicting iron deficiency nor for ameliorating the problems if they occur.

ALUMINUM

SOUTH COAST

The earliest documented work on the effect of aluminum on crop growth in south coastal British Columbia related to a problem of reduced production of raspberry. Harris (1936) suggested from soil analyses that "soil acidity, with iron and aluminum in particular, as possible reasons for poor growth" and that available aluminum was present "in sufficient quantities to cause severe injury to plants". Liming was suggested as a means to reduce the availability of the aluminum. In a follow-up study, aluminum was included as a treatment on raspberries grown in sand culture but did not cause an effect (Harris 1940). Atkinson and Wright (1942) could not find a relationship between exchangeable bases, including aluminum, when soil samples from "poor" versus "good" raspberry fields were compared. About thirty years later, aluminum was included in raspberry leaf tissue analyses studies (John, Carne and Eaton 1971), but the biological meaning of these analyses is difficult to determine, since subsequent work showed that many factors (date of sampling, type of tissue sampled, genotype, etc.) influence the concentrations (John and Daubeny 1972, John, Daubeny and Chuah 1976). Similarly, many factors influenced the aluminum (and other nutrient) concentration in strawberry leaves (John, Daubeny and McElroy 1975, 1976). Until further research work derives a suitable diagnostic procedure for these crops, leaf tissue analyses cannot be used to definitively assess the aluminum status of raspberries and strawberries.

Other plant response studies on aluminum have been related to soil pH and/or liming. Eaton and John (1971) considered aluminum in a liming study with peas, but since the major influence was due to manganese, aluminum analyses were not examined in detail. John, Case and Van Laerhoven (1972) observed that liming seven south coastal soils under growth chamber conditions resulted in increased yield and growth rate of alfalfa and concluded that "reductions of aluminum and manganese toxicities were the major factors responsible". Soil aluminum extracted by several extractants and their relationships to yield were significant (r = -0.33 to -0.42), and decreased as soil pH increased after limestone application (Table 6). The decrease of $CaCl_2$ extractable aluminum was less pronounced because of the relatively small concentration extracted (from 8.1 to 0.6 ppm) from all soils at all pHs. The correlations of the three extractants with the aluminum concentrations of the tops (r = 0.57 to 0.86) and the roots (r = 0.33 to 0.38) were all significant and the best overall extractant for both plant parts was with KCl (John et al 1972). Hoyt and Webber (1974) concluded that "$CaCl_2$-soluble aluminum was better correlated with crop data then exchangeable aluminum (2 N NaCl)" in a greenhouse study of 33 Canadian surface soils with a pH (0.01 M $CaCl_2$) range of 3.65 to 4.98 using rapeseed and barley as test crops.

Aluminum has been included in exploratory studies on the nutrient status of forest trees of south coastal British Columbia, but has not been considered to be a major problem (Carter, Otchere-Boateng and Klinka 1984, Carter, Scagel and Klinka 1986, Davis 1987). These studies utilized surveys and foliar analysis.

Several plant-oriented studies have included aluminum analyses to help interpret results even though that nutrient was not the primary focus of the study. Furnace slag, which contained aluminum and other nutrients, increased growth of red clover but the exact reason for the beneficial effect of the slag was not determined (Beaton, Speer and Harapiak 1968). Fumigation of a muck soil decreased the aluminum concentration of carrot foliage, but had a very small effect on that in the roots (Maurer and John 1971). Lead (John and Van Laerhoven 1972), cadmium (John 1976) and boron (John, Chuah and Van Laerhoven 1977) influenced the aluminum content of crops, but the universality of the effect was not established because of the limited work and general scope of the studies. Aluminum has been shown to influence the analysis of other elements. Aluminum concentrations greater than 3,000 ppm interfered with the azomethine-H colorimetric analysis of boron in soil and plant samples (John, Chuah and Neufeld 1975), but Kowalenko (1979) found that aluminum decreased the interference of fluoride in the modified curcumin colorimetric analysis of boron.

Studies that focused more on soil than plant aluminum have also been conducted. Harris and Woods (1935) documented the iron and aluminum oxide content (10.83%) of a soil used for raspberry production. Subsequent work assumed that soil sterilization had little or no effect on the availability of aluminum, since semi-quantitative analysis of aluminum measured in "displaced

Table 6 Comparison of total above ground alfalfa yield with pH and aluminum extracted by N NH_4Ac at pH 4.8 (ALAC), N KCl (ALKCL) and 0.01 M $CaCl_2$ (ALCA) after plant growth in Fraser Valley soils limed to specific base saturations (adapted from John, Case and Van Laerhoven 1972)

Soil	Liming treatment	Yield (g/pot)	pH	Aluminum (ppm Al) ALAC	ALKCL	ALCA
Ladner	No lime (40% sat.)	5.7	4.8	180	120	8.2
	To 70% base sat.	19.9	5.5	135	7	2.2
	To 100% base sat.	22.7	6.3	68	1	1.8
Hazelwood	No lime (30% sat.)	8.3	4.8	170	58	0.8
	To 40% base sat.	14.1	5.1	142	41	1.0
	To 70% base sat.	20.2	6.0	66	1	0.9
	To 100% base sat.	24.7	6.8	28	1	0.9
Monroe	No lime (63% sat.)	13.7	5.2	35	8	1.0
	To 70% base sat.	22.9	5.5	28	4	0.8
	To 100% base sat.	25.2	6.6	13	2	0.8
Fairfield	No lime (46% sat.)	8.6	5.1	66	26	1.4
	To 70% base sat.	16.7	5.9	47	4	1.0
	To 100% base sat.	23.0	7.0	12	2	1.2
Whatcom	No lime (20% sat.)	9.7	5.4	203	24	1.1
	To 40% base sat.	12.1	5.8	163	8	1.2
	To 70% base sat.	19.5	6.3	108	3	1.0
	To 100% base sat.	18.8	6.8	84	2	0.8
Marble Hill	No lime (24% sat.)	7.4	5.6	162	14	1.0
	To 40% base sat.	12.9	5.9	107	5	0.6
	To 70% base sat.	10.6	6.6	73	3	0.6
	To 100% base sat.	14.1	7.1	60	2	0.8
Annis Muck	No lime (22% sat.)	17.8	4.4	97	64	1.4
	To 40% base sat.	21.7	5.0	80	17	1.2
	To 70% base sat.	23.8	5.7	48	4	1.0
	To 100% base sat.	23.0	6.1	29	2	0.9

soil solution" were not influenced by sterilization. Clark (1964) showed a relationship between fixation of aluminum and exchangeable hydrogen in soils. This has implications for the liming requirement of soils (Clark 1965). Levesque (1974) observed that the selenium content of soils was closely related to ammonium oxalate extractable aluminum and iron and also soil organic carbon. Gu (1986) showed that iron and aluminum oxides had an indirect influence on the adsorption of boron in soils. Ali (1975) showed that the amount of aluminum extracted, by various methods was similar to the manganese extracted and that pretreatment (drying, freezing, storing) can cause unpredictable changes in the amounts extracted. The general survey of minor elements in Canadian soils provided various relationships among the elements and other factors (McKeague, Desjardin and Wolynetz 1979, McKeague and Wolynetz 1980), but samples from only seven sites in British Columbia were included.

Aluminum has also been considered from the viewpoint of genesis of soils (Lavkulich, Bhoojedhur and Rowles 1971, Sanborn and Lavkulich 1989) and has frequently been included as an analysis of representative soils in soil survey reports (Kelley and Spilsbury 1939, Day, Farstad and Laird 1959, Luttmerding 1981). The distribution of aluminum in soil profiles may indicate the degree of weathering that has occurred.

Research in south coastal British Columbia has shown aluminum toxicity can occur and this has been closely linked to soil pH and liming. Several extraction methods have been shown to be promising as a means of predicting potential toxicity problems, but less work has been done on the accumulation mechanisms in the plant. There has been considerable interest in aluminum chemistry in relation to soil genesis and classification. Studies have also shown that aluminum can influence nutrients such as iron and boron, and toxic metals such as lead and cadmium. These relationships to soil genesis and plant nutrition show the importance of further understanding this element and its chemistry in south coastal soils.

INTERIOR - HORTICULTURE

The earliest reported interest in aluminum in interior soils used for horticultural production was related to soil genesis and survey. Kelley and Spilsbury (1949) reported that aluminum, together with iron and magnesium, appeared to have been sorted by water since the clays of certain Okanagan and Similkameen soils had greater proportion of these elements in relation to silica. Sprout and Kelley (1964) concluded that there was little evidence for aluminum and iron movement in Black and Brown Wooded soils in the Kettle River Valley and Boundary District. Total aluminum oxide analyses of soils in other interior areas that could be used for horticultural production were recorded in survey reports, but the values were not interpreted further (Kelley and Sprout 1956, Kelley and Holland 1961).

The identification of significant acidification of orchard soils has resulted in renewed interest in aluminum. Ross, Hoyt and Neilsen (1985) found that acidification of five Okanagan apple orchard soils resulted in increased exchangeable and 0.02 M $CaCl_2$ extractable aluminum and decreased mineral crystallinity as shown by an increase in aluminum, silicon and iron oxides (tiron extraction). Hoyt and Neilsen (1985) found that trunk circumferences of three apple cultivars ("Delicious", "Tydeman", and "Rome Beauty") were negatively correlated with 0.02 M $CaCl_2$ extractable aluminum and manganese, but that this correlation did not occur with "McIntosh" cultivar. Neilsen, D., Hoyt and MacKenzie (1986) found that 1.3 to 15% of the zinc in interior orchard soils was associated with iron and aluminum oxides, showing that changes in aluminum forms due to soil acidification can have both direct and indirect effects on fruit tree production.

Published research information shows that increased availability of aluminum due to soil acidification may result in additional problems for fruit tree production in the interior of the province. It is possible that increased solubility of aluminum seriously inhibits root growth of apple trees, especially "Delicious", as has been reported for many other crops. This problem can be addressed by liming these soils. Future consideration should, however, be given to the possibility of lime-induced micronutrient deficiency.

INTERIOR - FORAGE

There is relatively little data published on aluminum for soils in the interior of British Columbia which are used for forage production. Soil survey reports included some extractable aluminum values as characterization data, but these were not interpreted and in many cases the precise method of determination was not given (Kelley and Farstad 1946, Farstad and Laird 1954, Runka 1972, Cotic, Van Barneveld and Sprout 1974, Lord and Mackintosh 1982, Dawson 1989). The limited number of interior soil samples (usually one) that included toxic metal (including aluminum) analyses makes it difficult to determine the importance of aluminum for forage crop production of the area (Hoyt and Nyborg 1971a, Hoyt and Nyborg 1972, Hoyt and Webber 1974). Ruckle (1977) documented aluminum analyses of vegetation from a wet meadow in south central British Columbia (Celista), but the data is too limited to make any general conclusions for soils of the area. Soils of this area tend not to be very acidic and are not used for intensive crop production, making aluminum a low research priority.

PEACE RIVER

Aluminum toxicity problems in Peace River soils of British Columbia have been widely known and studies concerning acid soils in Canada have frequently included samples from that region. Hoyt, Hennig and Dobb (1967) concluded that aluminum extracted by dilute HCl provided a relatively good indicator for the yield response of barley and alfalfa to liming. Although there was an inverse relationship between pH and acid extractable aluminum, the aluminum analysis gave a better prediction of the lime response than did pH. A subsequent study, where several extractants for available aluminum were considered showed that 0.01 M $CaCl_2$ extraction appeared to give the best correlations with plant response (Hoyt and Nyborg 1971a). Further work showed that the $CaCl_2$ extractable aluminum was essentially soluble aluminum and therefore the extractant had potential for determining potential toxicity on low pH soils (Hoyt and Nyborg 1972, Hoyt and Webber 1974, Webber, Hoyt and Corneau 1982, Hoyt and Nyborg 1987). Plants commonly grown in the Peace River area were shown to vary in their sensitivity to soil acidity and hence probably excessive aluminum (Elliott et al 1973). Optimum atomic absorption method for analyzing soil aluminum extracts were examined using a sample from the Peace River area (Webber 1974). Other studies determined the extent of the soil acidity problem from soil test data (Penney et al 1977) and measured the influence of acidity (including aluminum toxicity) on nitrogen mineralization (Nyborg and Hoyt 1978). Since values in a soil survey report of the Peace River area of British Columbia included only total and not extractable (i.e. available) aluminum in representative soils (Farstad et al 1965), these are useful for soil genesis interpretation rather than for aluminum management considerations.

SUMMARY

Although aluminum is not considered to be an essential nutrient, it can influence crop growth by either accumulating in toxic quantities in the plant or by influencing other nutrients. Aluminum toxicity has been shown in many areas of British Columbia, almost always associated acid soils. Some research has been conducted on extraction methods for predicting aluminum toxicity, but these have not been adopted for practical application. An understanding of aluminum chemistry in the soil would help in the development of management practices that would minimize problems of excessive available aluminum. Since the availability of aluminum, manganese, iron and zinc all tend to increase as soil pH decreases, all four elements should be considered in any studies on plant nutrition in acid soils or when management practices influence the pH of the soil.

MOLYBDENUM

SOUTH COAST

Molybdenum for south coastal crop production was considered in general micronutrient studies as early as 1949 (Gregory 1947). In that early study, molybdenum did not affect nodulation of Trifolium pratense. Subsequent work focused on plant seeds. Phillips (1952) found a molybdenum effect on red clover and pole bean seed yield, but the effect also required boron application. Bonin and Routley (1952) found, in a survey of British Columbia, that legume seeds contained a higher concentration of molybdenum than brassica seeds and that certain areas of the province "tended to produce seed of lower molybdenum content than others". Kynaston (1953) found that seed of a variety of plants treated with a micronutrient solution, which included molybdenum, resulted in variable (deleterious, beneficial and no) effects on germination. Subsequent to the work on seeds, molybdenum was considered in general nutrient studies of small fruits. Gold (1959) was not successful in producing visual symptoms of molybdenum deficiencies in strawberry as was accomplished for boron, manganese, zinc and copper deficiency symptoms. Molybdenum was measured in raspberry leaves in a survey study (John, Carne and Eaton 1971) and in a sampling methods study (John and Daubeny 1972), but the data was too limited to evaluate the status of this (or any) micronutrient in soils of the Fraser Valley for raspberry production. Maas (1975) did not find a response by Vancouver Island organic soils to a combined "minor element" application.

John, Case and Van Laerhoven (1972) appeared to have been concerned about the molybdenum content of coastal soils in a liming study carried out in pots since it was included in a general fertilizer amendment (0.83 ppm Mo was applied). The molybdenum content of alfalfa leaves (ranging from 1.2 to 40.0 ppm) of plants grown on these amended soils was assumed to have been adequate for growth, when compared with the critical concentration (0.5 ppm) reported for alfalfa in the literature (John et al 1972). The study did not report what the leaf content would have been without molybdenum amendment of the soil. Lime application increased the molybdenum concentration in the plant despite an increase in yield with liming. The authors discussed a concern for the resulting quality of the forage produced in relation to excessive molybdenum concentrations and the copper/molybdenum ratio. Concurrent studies on molybdenum in forages for ruminant feeds showed that the molybdenum contents of British Columbia feeds were frequently low, with 35% of the samples analyzed containing less than 1 ppm (Miltimore and Mason 1971). Likewise 19% of the copper/molybdenum ratios of these samples were less than a desired ration of 2.0. Peterson and Waldern (1977) concluded that the copper/molybdenum ratio was associated with unsatisfactory reproductive performance of dairy cattle in the Fraser Valley. Cathcart, Shelford and Peterson (1980) did not consider molybdenum to be a major concern for the quality of dairy cattle feed in general. Reports have provided molybdenum analysis data for feeds in the province (Soder 1984) or the south coast only (Anonymous 1984b, 1984f) but the values were not interpreted. In a greenhouse study, Czerwinski (1979) did not detect an increase in yield from molybdenum application but did detect an increase in the accumulation of the element in timothy and sweetclover plants used in the test.

Beaton, Speer and Harapiak (1968) showed that molybdenum was present in furnace slag and that the slag could be a good liming material, but the benefit arising from the molybdenum in the slag was not evaluated. Maurer and John (1971) also reported the molybdenum concentration of carrot roots and tops grown in fumigated soils, but no assessments of this data were made. Warren et al (1971) showed that the molybdenum content of vegetables could vary 500-fold, but since so many factors (soil pH, organic matter content, climate, etc.) influenced the content of this element, little could be said about potential pollution problem areas.

There is relatively little data published on molybdenum analysis of coastal soils. Chae and Lowe (1976) and Warren (1975) indicated limited total molybdenum data and no information on extractable/available soil molybdenum.

Although molybdenum analyses have been included in various soil-plant and animal feed studies in south coastal British Columbia, the data generated is insufficient for determining whether molybdenum is adequate for general crop yield and crop quality for animal production. There is a dearth of soil analysis data, and what is available is only for total and not extractable or available molybdenum.

INTERIOR - HORTICULTURE

There is no information on crop molybdenum needs for intensive cropping areas of the interior of the province. In addition to the provincial survey information on soils (Chae and Lowe 1976, Warren 1975) and vegetables (Warren et al 1971), Kelley and Holland (1961) reported some semiquantitative soil analyses. Neilsen et al (1989a) reported the molybdenum content of effluent in a trickle irrigation study but no plant molybdenum analyses were conducted. Van Netten and Morley (1983) found that molybdenum readily accumulated in radish plants when grown in soil samples from Summerland area that were uranium-rich. The accumulation of molybdenum tended to be greater from samples of high (7.6-7.8) than low (5.6) pH. The soil samples contained from 1 to 110 ppm total molybdenum, with the highest amount in the sample with the lowest pH. Little can be concluded about the molybdenum status of soils for intensive crop production from this limited amount of data available.

INTERIOR - FORAGE

Early research related to molybdenum for forage production in the interior of the province investigated the effect of molybdenum (and other micronutrients) on nodulation of *Trifolium pratense* (Gregory 1947). That study showed little response to molybdenum application. Cooke (1949) reported an increase in the growth of leguminous plants in response to molybdenum in a greenhouse study with sand and soil systems. Bonin and Routley (1952) documented variable but occasionally low amounts of molybdenum in legume and brassica seeds from plants grown in the province. Kynaston (1953) showed that micronutrient treatment of seed resulted in variable effects on the germination of various forages. Mason (1964) reported considerable response by alfalfa in the Armstrong area to molybdenum application. However, negligible responses to micronutrient applications that included molybdenum were reported by Pringle and Van Ryswyk (1965) for water sedge in a growth room study with peat soils, by Freyman and Van Ryswyk (1969) for pinegrass in pot and field trials on Grey Wooded soils, and by Czerwinski (1979) for timothy and sweet clover in a greenhouse study. The latter study did show with plant analyses that molybdenum uptake was increased by application to the soil of this nutrient.

A number of studies have considered molybdenum analysis for forage quality concerns in the interior. Miltimore et al (1964) concluded that, although a copper deficiency in cattle was due to low copper in the forage, the ratio of copper to molybdenum was an important contributing factor to the problem. Fletcher and Brink (1969) found that areas of south central British Columbia containing molybdenum ore bodies had range forages of only normal and not excessive molybdenum concentrations. Tingle and Dawley (1972) also observed that central British Columbia cereal forages were low in molybdenum despite molybdenum deposits in that area. They noted that low molybdenum occurred whether the copper content was high or low. Lowe and Bomke (1982) concluded that a copper deficiency problem with livestock raised in the Vanderhoof-Fort Fraser area was at least partly due to the high molybdenum content of the forage grown there. The high molybdenum caused the Cu/Mo ratio to be less than 2, which is considered to be critical for the copper requirement of livestock. Molybdenum in uranium-rich soils from the Summerland area was shown to be quite readily available to barley and oats since there was net "bioaccumulation" (Van Netten and Morley 1982a, 1982b). The molybdenum concentration in the plants was sufficiently high to be excessive for animals. In the study with oats (Van Netten and Morley 1982b), molybdenum uptake by the plant tended to be greater when the soil pH was slightly alkaline (pH = 7.4-7.9) than when it was acid (pH = 3.0). Total molybdenum in the samples used in the two studies ranged from 1 to 200 ppm. Pringle, Dawley and Miltimore (1973) assumed, from chemical analyses of corn silages grown in the interior of the province, that these crops were adequately supplied with copper and molybdenum. Several research studies (Van Ryswyk, Hubbard and Miltimore 1973, Miltimore et al 1973, Miltimore, Kalnin and Clapp 1978) and summaries of feed analyses (Anonymous 1984a, 1984c, 1984d, Soder 1984) documented molybdenum analyses of a wide variety of forage materials from the interior with little comment. From the lack of comment on forage quality, molybdenum was not considered a general nor major nutritional problem.

Reports of the molybdenum content of soils, either as total or extractable amounts, are quite scarce for interior soils used for forage production (Chae and Lowe 1976, Warren 1975, Van Netten and Morley 1982a, 1982b). This dearth of information contributes little to the interpretation or extrapolation of the forage analysis data.

There is little evidence for widespread molybdenum deficiency for forage crop production in the interior of the province. One field study reported some preliminary evidence of crop response to molybdenum application but several pot studies that included molybdenum together with other micronutrients did not document a crop yield response. Plant analyses suggest that, despite the probability of relatively large quantities of molybdenum in soil parent materials, it is not always readily available for crop uptake. There was early concern for the influence of molybdenum on nitrogen fixation by legumes but this has not been followed-up. It is evident that there is insufficient research data on which to base conclusions on the molybdenum status of interior British Columbia range soils.

PEACE RIVER

There is relatively little data on the molybdenum status of Peace River soils of British Columbia. Chae and Lowe (1976) do not report any values for the Peace River area in their literature survey of trace element analyses of parent materials. Early greenhouse (Gregory 1947, Czerwinski 1979), seed germination (Kynaston 1953), seed analyses (Bonin and Routley 1952) and forage (Miltimore and Mason 1971, Pringle, Dawley and Miltimore 1973, Anonymous 1984e, Soder 1984) studies provide very limited and dated information on which to make any practical conclusions regarding molybdenum.

SUMMARY

The small amount of research data published on molybdenum for British Columbia crop production is inadequate to determine whether or not this nutrient is a problem. The majority of the work that has been done has been for interior forage production areas. There has been one early preliminary report of a crop response to molybdenum application but this has not been considered further. Likewise, an early concern for the effect of molybdenum on nitrogen fixation has not been followed-up.

CHLORINE

Relatively little is published on chlorine for British Columbia crop production. The reports published tend to be for the intensively cultivated areas, namely the south coast and the Okanagan. On the coast, the first report on chlorine was that by Harris and Woods (1935) who measured chlorine in a study of the "soil solution" in raspberry plantings. Chlorine did not show a consistent behaviour and values ranged from 10 - 48 ppm Cl. However, they noted that "it is noticeable that it is high during the early spring when other ions are low, so it is probably a product of rainfall" and "during the summer months cover crops seem to reduce it more than other treatments, and clover more than the other cover crops". They did not report any relationship to raspberry growth or yield. Freeman (1950) concluded that carrot root production on Monroe soil at Agassiz Research Station was detrimentally affected by the inclusion of chlorides in the fertilizer mix. He did report that the top to root ratio of chlorine in the crop increased rapidly as chloride application increased. Chlorine also reduced the formation of carotene (Freeman and Harris 1951). Beaton and Speer (1961) reported that "Cl^- level did not have any significant effect except for the second harvest where yields for the treatments with 75 lb of Cl^-/acre were significantly lower than for both the 0 and 150 lb. applications" in a growth chamber experiment with bromegrass growth on the C horizon of the same Monroe soil. Beaton, Speer and Harapiak (1968) documented the chlorine content of Kimberley electric furnace slag, in a study of its use as an amendment for clover grown on two coastal soils, but the relationship of chlorine to crop response was not explored. Spring chloride application, as potassium chloride fertilizer, did not influence yield or disease resistance of winter wheat grown at three locations in the south coast in 1988 (Xie and Bomke 1989). Chloride application increased the chloride concentration in the plant and soil. The chloride content of soils in control treatments in a June sampling were 11, 13 and 18 ppm at Oyster River, Chilliwack and Delta locations, respectively.

In a survey report of soils in the Okanagan and Similkameen Valleys, Kelley and Spilsbury (1949) concluded "the deficiency of chlorides would appear to be general in the Okanagan Valley" from the very low ("trace") quantities found in soil analyses. However, the postulation does not appear to have been followed up. Chlorine (110-115 ppm) was shown to be present in an Okanagan municipal waste water used for irrigating apple trees (Neilsen et al 1989b). Despite the known sensitivity of most fruit trees to excess chloride, no adverse salinity effects on growth or nutrition were detected, including the contribution of chlorides or sodium, after five years of wastewater irrigation of sweet cherry (Neilsen et al 1991). The study, however, did not report leaf chloride concentration.

It is difficult to draw a conclusion about the chlorine status of British Columbia soils from the very limited research data that is presently available. The concern for chlorine, as shown by the studies that have been conducted, may be particularly important for areas growing high value crops and receiving considerable precipitation or irrigation (high leaching potential) such as for the coast and Okanagan areas. These areas utilize relatively large quantities of mixed fertilizers, hence adequate chlorine may be supplied unintentionally. However, some research specifically on chlorine may be warranted, in order to understand the optimum fertilizer types to use for both quantity and quality effect on yield and to assess any potential for the accumulation of excessive quantities.

COBALT

Cobalt is not considered to be essential for crop growth, but because it is required by animals, the quantity of this element in forages is important for feed quality. It has been concluded from analysis of soils of the Fraser Valley (Kitson 1949) and of the Upper Columbia Valley (Kelley and Holland 1961), and from visual cobalt deficiency symptoms in sheep in certain areas of the central interior (Farstad and Laird 1954), that there are areas of the province where the cobalt content is quite low and could present a problem for animal production. A number of reports document cobalt analyses of soils or soil materials in the province (Kelley and Farstad 1946, Chae and Lowe 1976, McKeague, Desjardin and Wolynetz 1979, McKeague and Wolynetz 1980, Schreier 1987, Schreier, Omueti and Lavkulich 1987), but did not relate these analyses to plant uptake or availability to animals. Thus it is difficult to make specific conclusions. Likewise, a report of cobalt in furnace slag which can be used as a soil amendment (Beaton, Speer and Harapiak 1968) is too limited for evaluating any cobalt influence on plant forage quality. Bomke and Lowe (1991) measured 8 ppm cobalt in deep-pit poultry manure but were unable to adequately measure the low concentrations of cobalt in forage samples. These forages were grown in two soils (one from Chilliwack and one from Prince George) in a pot study with manure applications up to 40 t/ha. They were, however, more concerned about possibilities of toxic accumulations rather than nutrient requirements or deficiencies. It is probable that cobalt has not been examined very extensively in soils in relation to crops and animals in British Columbia because animal deficiencies can be easily treated with salt provided for the animals. Cobalt is required by Rhizobium and, therefore, low cobalt may have implications for legume production and survival.

SELENIUM

Selenium, like cobalt, is not an essential element for crop growth but is required by animals. As a result, concerns for the selenium status of British Columbia soils is related to animal feeds and therefore reports are largely confined to forage production systems. Based on a forage survey, Miltimore (1971) was the first to show that selenium deficiency was a problem in many parts of the province. The concentration varied considerably within and between regions, but low selenium was relatively frequent. This was subsequently confirmed in another survey (Miltimore et al 1975), and it was further concluded that there was little danger of selenium toxicity. Since feeds grown in one area are often transported for use to another area, this problem is a provincial concern. Carter et al (1968), in a study of the entire Pacific Northwest including British Columbia and the state of Washington, projected that forages in British Columbia would be low to very low in selenium content. Taylor, Puls and MacDonald (1970) showed that selenium deficiency probably contributed to many of the bovine abortions that have occurred in British Columbia and also the State of Washington. Summaries of laboratory analyses provide documentation of the range of selenium in feedstuffs in the province (Anonymous 1984a, 1984b, 1984c, 1984d, 1984e, 1984f, Soder 1984).

There have been two studies considering selenium (and other factors) for dairy production specifically for the Fraser Valley. Cathcart, Shelford and Peterson (1980) concluded, from mineral analyses of feed, that "the vast majority of forages contain inadequate Se". Peterson and Waldern (1977) found that Se in grain was at least partially associated with unsatisfactory reproductive performance of dairy herds.

In the interior of the province, Miltimore et al (1973) did not detect an improvement in gain of beef cattle in response to selenium (and copper) injections when pastured on "mineral and organic groundwater" soils. Fenimore, Adams and Puls (1983) found that livestock fed "local hay during the winter or grazed on fertilized/irrigated pastures" in the Windermere Valley were low to deficient in selenium. Hay from 10 ranches averaged 0.03 ppm selenium which would have been sufficiently low to result in "Se-vitamin E deficiency disease. Fletcher and Brink (1969) had previously shown that forages from south central British Columbia had less than 1 ppm selenium. Acland (1972) concluded that there was an apparent loss of selenium from plant material during oven drying, storage and acid digestion, which suggests that selenium analysis data should be treated with caution unless these factors are considered. Although most studies have been concern with low selenium concentration, Cooke (1949) showed that application of selenium under certain circumstances could detrimentally affect alfalfa growth.

Several soil studies have been reported where selenium was analyzed. Levesque (1974), studying 54 soil profiles from across Canada which included five from British Columbia, showed that total selenium distribution was "closely associated with both organic carbon and ammonium oxalate extractable iron and aluminum". Although the reports of Chae and Lowe (1976), McKeague, Desjardin and Wolynetz (1979) and McKeague and Wolynetz (1980) provide some data on the selenium content of soils in British Columbia, this should be extrapolated to crop availability carefully since Van Ryswyk, Broersma and Kalnin (1976) found that the selenium content of alfalfa was not well related to total selenium in the soil. Other factors, such as soil pH and moisture regime appeared to have had a greater effect than total soil selenium on the concentration in the plant. Van Netten and Morley (1983) did not observe bioaccumulation of selenium in radish plants when they were grown in uranium-rich soil samples from the Summerland area. The samples contained 0.5 to 15 ppm total selenium. Recently, Bomke and Lowe (1991) found that, although deep-pit manure applications up to 40 t/ha did not significantly affect whole-plant barley selenium concentrations (10-31 ppm), the uptake of selenium increased along with the increase in crop yield. The data was insufficient to determine whether the manure supplied the increased selenium or increased the availability of soil selenium or both. The study was conducted in pots using a clay soil from near Prince George.

It is well established that low selenium in livestock feeds in British Columbia is a problem, but neither the specific locations of low total or available selenium in soils nor the factors that could alter selenium uptake by plants are well defined. More research would be needed on these aspects in order to develop management practices to minimize the problem. If the problem is serious, the most suitable method for supplementing cattle feeds could be administered directly to the animal, added to the feed or applied to the soil or growing plant as a fertilizer. Both economic and environmental factors would have to be considered in deciding which method of selenium treatment should be used.

GENERAL SUMMARY AND CONCLUSIONS

Micronutrient use in British Columbia agriculture has received research attention for many years but this research has been sporadic rather than well organized and focused. This is partly due to the distribution, diversity and relative intensity of agricultural activity in the province. Some micronutrient fertilizers are being used regularly and their use has generally, but not consistently, increased. Two concerns are evident with respect to micronutrients, namely the direct effect of the element on plant growth (e.g. yield increase or decrease, changes in visible quality) and the indirect effect on animal production. In certain cases, a micronutrient is essential for both plants and animals but animals require a relatively greater concentration of that nutrient than plants for normal growth. This is the case for copper, zinc, manganese, iron and molybdenum. In other cases, a micronutrient is essential for the animal but not for the plant (i.e. cobalt and selenium). In the interior of the province where grazing is the main focus of livestock production, poor feed quality has been identified by insufficient copper, zinc, manganese, molybdenum, cobalt and selenium concentrations. Although copper, zinc and manganese deficiencies may also reduce plant yield besides quality, it appears that the most efficient method of ameliorating the problem under extensive management is through direct supplementation to the animal. However, an understanding of the distribution and availability of micronutrients in various soils of concern for animal production would be useful in developing economic management practices to minimize deficient situations.

Direct plant responses to boron, zinc and manganese and to a lesser extent iron, molybdenum and chlorine, have been well documented in specific areas of the province, particularly the south coast and interior areas that produce crops under intensive management practices (e.g. horticultural crops). Boron deficiency appears throughout the province and fertilization with this element is done fairly extensively. Soil testing (hot water extraction) and, to a more limited extent, leaf tissue testing is being used for predicting deficient situations of boron but documented local research to support these methods are somewhat limited. Zinc and manganese deficiencies as well as excesses have been documented in both the south coast and the horticultural areas of the interior. Considerably more research has been conducted on zinc for tree fruits in the interior. Leaf tissue standards have been defined for these crops and foliar spray techniques examined. Some soil-oriented research has been conducted on zinc and manganese but the information is insufficient to adequately derive a soil test procedure. The soil research, however, has clearly shown that soil pH greatly influences the availability of these elements, with greater availability occurring in acid conditions. With accelerated acidification occurring in both of these areas due to intensive management practices and application of lime, soil pH must be incorporated into the prediction system. It is possible, for both zinc and manganese, that one soil extraction may not be suitable for determining both deficiency and toxic situations. Iron deficiency has been observed in the Okanagan and Similkameen Valleys and has also been associated with high soil pH. Since aluminum toxicity is also greatly influenced by low pH, it is recommended that research on zinc, manganese, iron and aluminum be closely coordinated.

Since there is little direct research on the yield response of crops to copper, molybdenum and chlorine, their status in British Columbia soils cannot be adequately determined. A consistent and focused research program would be needed to resolve whether fertilization with these elements would be beneficial.

It is evident that various micronutrient problems exist in the province but the research data available to clearly define these instances are limited. Because of the diversity of agricultural activity in the province, considerable research would be required. Some of the research (such as soil extraction) could be coordinated over the entire province but much of it would have to be specific to certain areas or crops. In any case, a consistent and sustained research program would be needed. Once the problem areas are defined, research will be needed to examine optimum amelioration methods. Although research from other areas of the world may be pertinent, local evaluation is essential to provide confidence in their application, if indeed they are directly applicable.

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