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Technical Bulletin 1987-3E

An evaluation of nitrogen use in British Columbia agriculture

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An evaluation of nitrogen use in British Columbia agriculture

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Technical Bulletin 1987-3E

Research Branch
Agriculture Canada
1987

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Produced by Research Program Service

Cat. No. A54-8/1987-3E
ISBN 0-662-54839-6

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SUMMARY

A review of published research conducted in British Columbia showed that current nitrogen recommendations are largely supported by plant response data, with limited data on soils. As a result, the use of soil analysis for recommendations is theoretical. Comparisons of nitrogen fertilizer use with general recommendations showed that maximum rates of nitrogen are used in the Coastal and Okanagan areas, whereas significantly less than maximum recommended nitrogen fertilizer is used in the Interior and Peace River areas. When manure nitrogen is taken into account, rates of nitrogen well in excess of maximum recommendations are applied in the Lower Mainland and probably also in the Okanagan Valley. Research specifically aimed at the needs of each area of the province is required before extension work is conducted to either limit or increase nitrogen use. Soil nitrogen analysis should be included in future nitrogen research. Increased research should be conducted on biological fixation as a nitrogen source for crop production.

RÉSUMÉ

Une revue des recherches conduites en Colombie-Britannique révèle que les recommandations actuelles de fumure azotée sont basées essentiellement sur la réaction des cultures, et beaucoup moins sur l'état du sol, de sorte que les analyses de sol n'ont qu'une utilité théorique. La confrontation des pratiques de fumure avec les quantités recommandées montre que c'est dans la zone côtière et dans l'Okanagane que les doses maximales d'azote sont utilisées alors que dans les régions de l'intérieur et de la Rivière de la Paix on emploie des doses significativement inférieures aux doses conseillées. Si l'on tient compte de l'azote apporté par le fumier, le Sud-ouest de l'intérieur, et probablement aussi l'Okanagane, appliquent des doses d'azote bien au-delà des fumures maximales préconisées. Des recherches sur les besoins particuliers dans chaque région de la province s'imposent avant qu'on puisse entreprendre de restreindre ou, au contraire, d'accroître l'emploi de l'azote. Les recherches futures devraient tenir compte des résultats des analyses de sol. Il faudra également intensifier les recherches sur la fixation biologique comme source d'azote pour les cultures.

ACKNOWLEDGMENTS

This report is the direct result of activities of the soil fertility work group of the soil management subcommittee. The subcommittee reports to the Land Research Science Lead Committee of British Columbia. The author wishes to thank all the members of the work group (Mr. R.A. Bertrand, Dr. A.A. Bomke, Mr. N.A. Gough, Dr. W.A. Herman, Dr. L.E. Lowe, Mr. S. Loewen, Dr. G.H. Neilsen, and Dr. W. van Lierop) and other soil scientists throughout the province for their encouragement and technical contributions in the preparation of this report.

INTRODUCTION

General aspects of the cycling of nitrogen in agriculture are fairly well understood (Stevenson 1982). Many processes are involved. Each process responds differently to environmental factors and farm management practices, and therefore the cycling of nitrogen is quite site-specific. As a result, extrapolation of nitrogen application practices and research information from one area to another must be done with extreme caution. Local evaluation is necessary to determine that the most effective methods are being used. Agriculture in British Columbia is diverse and in many ways unusual in Canada because of the topography and climate. Both economic and environmental pressures require increased efficiency in the use of nitrogen. Actual and recommended use should be examined and compared to achieve an accurate assessment of use in British Columbia.

This report assesses current recommendations for nitrogen use by reviewing published reports of research conducted in British Columbia. Research journals are emphasized because they provide details of both methods used and interpretations, allowing the critical evaluation of data. A comparison is then made between actual and recommended use of nitrogen from available data. Although assumptions are required for the calculations, the data should provide an adequate evaluation of the relative distribution of fertilizer nitrogen use.

This evaluation of nitrogen use in British Columbia should provide a basis for improving current application practices through effective research and extension activities. It is hoped that the information is detailed enough to allow an exchange of knowledge and ideas within and beyond the borders of the province.

OVERVIEW OF AGRICULTURE IN BRITISH COLUMBIA IN RELATION TO NITROGEN USE

British Columbia has a diverse landscape and climate (Chilton 1981; Valentine et al. 1978), which has had a profound influence on the type and distribution of agriculture. The nitrogen cycle is dynamic and responds to climatic conditions. A general evaluation of nitrogen use in British Columbia would not be meaningful unless the diversity of agricultural activity is taken into consideration.

Because of the cost of nitrogen fertilizer sources, loss of nitrogen from agricultural production systems is a major concern. Loss of nitrogen can occur through leaching, denitrification, volatilization, and erosion. In all of these processes, with the possible exception of volatilization, the moisture regime is the dominant factor influencing transformations and movement. Moisture is used as the dominant environmental factor for discriminating agricultural activity in relation to nitrogen use in this review.

Census data from 1981 (Macey 1982), compiled for various census districts by regional district boundaries, were summarized into four larger areas: Coastal, Okanagan, Peace River, and Interior (Fig. 1). The Interior included

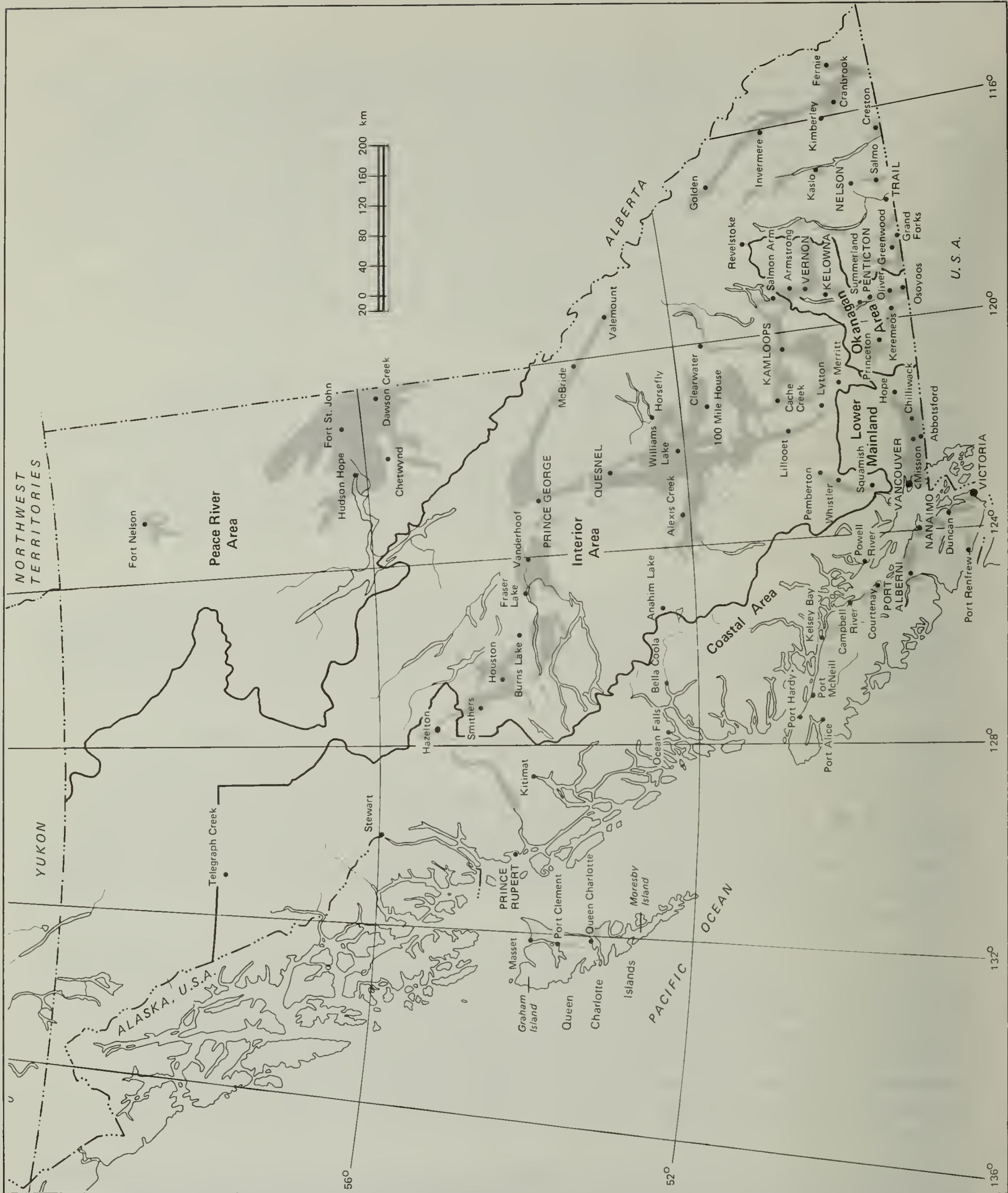

Fig. 1. Outline of grouping of census-reporting districts into four general areas of agricultural activity and approximate distribution of land in agricultural reserves (shaded areas) in British Columbia.

Table 1. Mean annual climate data for selected locations in British Columbia.

	Coastal		Okanagan	Interior			Peace River
	Vancouver	Prince Rupert	Summerland	Cranbrook	Revelstoke	Prince George	Fort St. John
Snowfall (cm)	52	113	74	178	412	233	206
Precipitation (mm)	1068	2415	296	438	1096	620	450
Evapotrans. (mm)	490	613	295	337	485	439	383
Temperature (°C)	9.8	7.8	8.9	5.1	7.2	3.3	1.3
Range from mean (°C)	15	12	25	27	25	27	33
Bright sunshine (hr)	930	1035	1990	1800	1600	1865	2130

Adapted from Schaefer 1978.

Table 2. Distribution of farmland and irrigation in British Columbia in 1981 and its average holding size and sales value.*

	Coastal	(Lower Mainland)	Okanagan	Peace River	Interior	Total
Total land†	21 934	(2 580)	2 146	19 506	45 675	89 310
Land in farms†	164	(101)	162	721	1 132	2 179
Improved farmland†	115	(81)	72	377	382	946
Irrigation†	13	(8)	28	-	60	101
Average holding size (ha)	20	(16)	38	385	206	109
Total value of product sales (millions $)	488	(424)	114	60	138	799

*Adapted from Macey 1982.
†In thousands of hectares.

Table 3. Distribution of major crop production in British Columbia in 1981.

	Coastal	(Lower Mainland)	Okanagan	Peace River	Interior	Total
Cereal grains	4 596	(3 440)	5 265	144 454	15 488	169 803
Corn	8 008	(7 466)	1 680	6	2 117	11 811
Alfalfa hay	1 752	(1 097)	16 893	28 272	69 009	115 926
Hay & other fodder	42 819	(27 932)	6 576	60 431	101 166	210 992
Vegetables	6 699	(6 211)	630	15	523	7 867
Tree fruits	289	(100)	10 437	-	791	11 517
Small fruits	4 260	(4 137)	1 239	2	78	5 579
Total (ha)	68 423	(50 383)	42 720	233 180	189 172	533 495
Proportion of improved farmland (%)	60	(62)	59	62	49	56

Adapted from Macey 1982.

a plateau, a trench, and mountains. These areas reflect both the moderate, wet climate of the coast and the warm, drier climate farther east (Table 1). Because of its agricultural significance, the Lower Mainland was considered as a special area within the larger Coastal area.

The statistics confirm that farms occupy only a small proportion of the total land mass of the province (Table 2). The Interior and Peace River areas tend to have extensive operations, with large holding sizes and a lower value of sales. The Coastal and Okanagan areas have smaller holding sizes and a high value of sales. This difference reflects the greater intensity of agricultural activity. The Lower Mainland tends to have the greatest intensity and generated over one-half of the total provincial sales of agricultural products in 1981. Irrigation is done not only in the Okanagan and Interior but also in the Coastal area. Despite the high precipitation on the coast, supplemental irrigation is used because of the low rainfall in July and August and the intensity of production.

Cereal grains and grasses constitute the major crops grown in the extensive agriculture of the Peace River and Interior areas (Table 3). The Peace River is the major cereal-grain-producing area of the province. Grass, corn, vegetables, and small fruits are the major crops grown in the Coastal area, with many other crops produced because of the favorable climate. The Lower Mainland is the most important area for vegetable and small-fruit production. Production of tree fruits tends to be concentrated in the Okanagan Valley area, but many other crops are also grown there. Alfalfa accounts for a large proportion of the hay produced there. Over one-half of British Columbia's cattle were in the Interior in 1981, since this area is particularly suitable for extensive animal production (Table 4). However, the Coastal and Okanagan areas have a significant number of cattle, despite the smaller area of farmland. Much of the intensive cattle production consists

Table 4. Distribution of the total number of cattle, hens, chickens, and pigs in British Columbia in 1981.

Area	Cattle	Hens and chickens	Pigs
Coastal	196 979	8 997 163	170 806
(Lower Mainland)	(159 027)	(7 991 733)	(158 937)
Okanagan	72 219	361 779	39 713
Peace River	81 649	64 281	15 125
Interior	438 994	475 240	28 230
Total	789 841	9 898 463	253 874

Adapted from Macey 1982.

of dairying. The Lower Mainland has a particularly high intensity of animal operations, with a large proportion of the hens, chickens, and pigs in the province as well as a significant number of cattle.

REVIEW OF NITROGEN RESEARCH CONDUCTED IN BRITISH COLUMBIA

Because agriculture in British Columbia is complex and nitrogen processes are influenced by weather conditions, the review of research conducted in the province was organized into nitrogen management units, which are based on natural and imposed moisture conditions. Many different types of moisture classifications are available. Clayton and Marshall (Bentley 1979) show that British Columbia contains all the soil moisture subclasses that they used for Canada. The subclasses include perhumid, humid, subhumid, semiarid, and subarid, depending on the varying periods and intensity of water deficit in the growing season. This report groups moisture conditions into "aridic" and "humidic" nitrogen management units, with no precise definitions proposed at this time. The aridic unit includes the interior of the province and the humidic the coastal area. The aridic study unit is further broken down into subunits, depending on irrigation practices (nonirrigated, irrigated for extensive crop production such as forages, and irrigated for intensive crop production such as fruit and vegetables). The humidic unit is not further subdivided, even though irrigation is used under some conditions.

Aridic - nonirrigated nitrogen management unit

The aridic - nonirrigated nitrogen management unit includes farms in the Interior and Peace River areas and in some parts of the Okanagan. Animal production is significant, making forage an important crop. Forages include native grasses, introduced grasses, and cereals. The production of cereals and oil seeds is largely confined to the Peace River area, but some of these crops are grown in various pockets throughout the management unit. Outside the Peace River area, Creston is the most important area for the production of cereals and oil seeds. Nitrogen research has been proportional to this distribution of agriculture.

Studies in the late 1950s showed that the quantity and quality of native grass (specifically, its protein content) could be increased substantially with moderate rates (67 kg/ha) of nitrogen application in the south Okanagan (Mason and Miltimore 1959). Beaton et al. (1960) found a poor correlation between nitrate accumulation during a laboratory incubation and measured forage production in the field. The study did show that nitrate production was low on all sites, but nitrogen fertilizer response trials were not included. The authors concluded that the wide range of climatic conditions probably contributed greatly to the poor correlation. Nitrogen application was shown to increase the seed yield of a native range grass (beardless wheatgrass) in the south Okanagan (Miltimore et al. 1962). This increased seed production was expected to be useful in restoring the dominance of a preferred grass species for eventual range improvement. A number of trials were subsequently conducted, showing that both yield and nitrogen content of grasses of open rangeland were increased by fertilizer application (Hall 1971; Mason and Miltimore 1964) and that in some cases there were residual effects

(Hubbard and Mason 1967; Mason and Miltimore 1969) for up to 10 years (Mason and Miltimore 1972). All these factors are important when the economics of applications are being considered. Pinegrass was also shown to respond to nitrogen applications (Freyman and van Ryswyk 1969). Pinegrass is an important summer grazing species that grows in forested areas. These forested areas have Gray Wooded soils and frequently respond to sulfur applications as well. A sulfur deficiency restricts nitrogen responses. Soil nitrate analysis of the pinegrass study showed little movement of nitrogen, even through the second season after application. A summary of research on rangeland fertilization concluded that nitrogen was the nutrient most frequently required for range grass production (Agriculture Canada 1971). That review concluded, in part, that more fertilizer trials were required on introduced species of grass and that inexpensive fertilizer application methods were required for the rough topography of rangelands.

Several studies have shown that introduced species of range grass such as meadow and creeping foxtail, timothy, and crested wheatgrass grown in central British Columbia respond readily to nitrogen fertilization (van Adrichem and Tingle 1975; Le Pine 1975; Williams et al. 1979; Broersma and Kline 1982; Kline and Broersma 1983). Both quantity and quality of the grass were improved. Timothy showed some preference to urea over ammonium nitrate, whereas reed canarygrass did not (Le Pine 1975). Nitrogen application was shown to increase water use efficiency (Williams et al. 1979), which is important under dry rangeland conditions. The nitrate content of plants was shown to increase with increased rates of nitrogen application, with meadow foxtail being the greatest accumulator (Broersma and Kline 1982; Kline and Broersma 1983). It was concluded that nitrogen at 120 kg/ha applied in the spring and 50 kg/ha applied in the summer would probably not result in nitrate accumulation to dangerous levels. A study showed that the crude protein content of timothy and meadow foxtail declined from 19 June to 23 August (advancing maturity) at Prince George (Waldie et al. 1983), but corresponding data on the accumulation of dry matter or the availability of soil nitrogen were not included. It is evident that as for studies on native grasses, nitrogen research on introduced grass species has been directed toward plants rather than soils.

Grass produced in wetlands is an important component of ranching in interior British Columbia. These areas are important for grazing and hay production, which is critical for over-wintering livestock. Since these areas are confined, they can be more intensively managed than rangeland. Fertilizer trials on wetlands, both in the field and growth room, showed that nitrogen could increase the quantity and quality of forage production (McLean et al. 1963; Pringle and van Ryswyk 1965, 1967, 1968; Mason and Miltimore 1970; van Ryswyk et al. 1973, 1974). This information and other, unpublished data were the basis for general fertilizer recommendations for both native and introduced grasses (Central Interior Forage Extension Committee 1981). Nitrogen applied annually in the fall at a rate of up to 84 kg/ha was recommended to reduce nitrogen losses. Most of the research was forage-based, and limited information on soil nitrogen has been published. The total amount of nitrogen in the soil reported for these studies was high, ranging from 2.3 to 3.0%, suggesting that most of it was not available to the crop under wetland conditions.

Ashby (1969) found that nitrogen encapsulated in perforated polyethylene as a means of controlling the rate of release was more effective than soil-applied nitrogen for ryegrass production in the greenhouse. He also showed that nitrogen and magnesium were mutually antagonistic in their release from the capsules. The technique is not in common use at this time, probably because of the high cost of the product.

Nitrogen research in the Peace River region has been geared toward soils rather than toward other areas of management, possibly because of the acceptance of the nitrate test for nitrogen fertilizer recommendations in the Prairie Provinces. However, crop production and soils in the Peace River region are somewhat different from those of the prairies. More grass, legumes, flax, and canola are included in the crop rotations, and the soils are more acidic. Early published information focused on the effect of fertilizer placement on crop production (Nyborg 1961; Nyborg and Hennig 1969). Seed row applications of fertilizer, including nitrogen, affected flax and rapeseed production more than barley, and placement away from the row as rates increased was required to reduce seedling damage. Cereal production following legume grown for hay was increased in some cases (Hoyt and Hennig 1971; Hoyt and Leitch 1983). Soil nitrogen measurements appeared to be useful in understanding the various responses. Soil nitrate nitrogen appeared to be a significant factor in barley production following various dates of breaking fescue sod (Hennig and Rice 1977). Acidification of Peace River soils has been shown to decrease crop yields. This discovery has implications for nitrogen fertilization because most nitrogen fertilizers are net acidifiers (Hoyt and Hennig 1982). Liming acid soils was shown to increase nitrogen mineralization and nitrification rates (Nyborg and Hoyt 1978). Studies on nitrogen fixation showed that it was decreased by low soil pH and was influenced by climate, season, and type of plant (Rice et al. 1977; Rice 1980).

A limited amount of cereal production is scattered in many locations in the aridic - nonirrigated study unit of the province. There are few published reports of nitrogen trials on cereals in the central and southeast part of the province. Gough (1984) did not obtain a yield response to nitrogen with spring wheat and spring barley at Armstrong or with spring barley at Creston. Soil nitrate, prior to planting, was relatively high (90-100 kg/ha to a depth of 50 cm) and may be the reason for a lack of yield response.

Little, if any, research is currently being conducted on nitrogen applications on native grasses or on introduced dryland and wetland grasses. It is generally assumed that there would be a good response, but operators are reluctant to apply fertilizer, except on introduced wetland grasses, because there is too much area to cover. In many cases it is more popular to extend the land base than to increase the intensity of the management. Fieldwork on a soil test correlation project that included nitrogen has been completed in the central interior, and the data are currently being assessed (Doggart et al. 1983). It is hoped that a soil nitrate test could be used for recommendations on fertilizer nitrogen. Some work is being conducted on nitrogen fixation by native species of vegetation.

Only a small amount of research is currently being done on nitrogen in cereals outside the Peace River area. The work consists mainly of fertilizer response trials in Creston and north Okanagan, where the possibility of using a nitrate test is of prime interest. At Beaverlodge Research Station, which is on the Alberta side of the Peace River area, scientists are studying the relationship between growth and distribution of barley root and nitrogen uptake from soils with a solonetizic B horizon, i.e., solods; uptake of other nutrients is also being investigated. Work is also continuing on nitrogen fixation by legume crops and availability of fixed nitrogen to succeeding crops.

<u>Aridic - irrigated - extensive nitrogen management unit</u>

Agricultural production in this management unit is sparsely distributed, occurring largely in the Okanagan and Interior areas, and is geared to forage grass production including grasses, alfalfa, and forage corn. All research on the nitrogen requirement of these crops is recent, and publication of data is limited. A technical report on field fertilizer response trials showed that nitrogen application tends to be the most important nutrient for yield increases in silage corn (van Ryswyk 1985). Soil nitrate was measured and appeared to be a good indicator for nitrogen recommendations. Although only surface (0-15 cm) samples were taken for the response trials, the relationship to yield response was quite good. Hilliard (1983) examined one location in detail, sampling soil on several dates during the growing season to a depth of about 100 cm. The results suggest that nitrate leaching of a treatment that contained a high rate of nitrogen (225 kg/ha) occurred during the growing season.

Nitrogen application appears to have influenced magnesium uptake by corn, with some evidence of induced magnesium deficiency (Broersma and van Ryswyk 1979). The effect appears to differ with the variety of corn and the weather.

Currently, scientists are discussing the implementation of an analysis of nitrate in the surface soil to determine how much fertilizer nitrogen is required by soils in this management unit. Because crops of relatively low value are involved and land area is not a constraint, researchers are seeking the most economical method of producing the greatest yield. The inefficient use of fertilizer nitrogen resulting from nitrate leaching would be a major concern, and therefore plant utilization is emphasized.

<u>Aridic - irrigated - intensive nitrogen management unit</u>

Nitrogen research in this management unit has been done mostly in the Okanagan area, although production is scattered in other aridic areas. Wilcox et al. (1947) documented early observations of fertilizer trials on five apple orchards in the Okanagan. The treatments at each location were not replicated, hence limiting any statistical treatment. However, the long length of the trials (10 years or more) should result in increased confidence in the conclusions. The report concluded that nitrogen would increase apple production in many Okanagan soils. It was speculated that a leguminous cover crop could provide the nitrogen required. Nitrogen applications appeared to increase tree vigor (trunk circumference and average terminal length), as well as yield and fruit size, but reduced fruit color. Conclusions on the effects of nitrogen fertilizer on the soil were limited because sampling was done in only 1 year (1940), and the small range of analyses did not include any nitrogen measurements. A decreased soil pH resulting from fertilizer application was observed. The problems caused by acidification were subsequently studied in more detail (Hoyt and Neilsen 1985; Neilsen and Hoyt 1982; Ross et al. 1985).

Subsequent work (Wilcox 1949) focused on terminal shoots as a possible diagnostic analysis of the nutrient status of apple trees. Evidently, length of terminal shoots was being used as a basis for recommendations in nitrogen fertilizer. Although significant correlations of the nitrogen content of the shoots with terminal length and yield were found, it was concluded that shoot analysis was not a suitable means of diagnosing the nutrient status of fruit trees. The nitrogen content of the shoot perhaps naturally increased, decreased, or fluctuated with time, making sampling time critical, and the range of nitrogen values perhaps was not large, despite wide variations in soil type and fertilizer treatments of the trees tested. It was suggested by the authors that analysis of leaf tissue might be more suitable.

From the mid 1960s (Mason 1964) to the present (Neilsen and Hogue 1985), analysis of leaf tissue has been accepted as a good indicator of the response of apple trees to fertilizer applications, including nitrogen. Research on nitrogen for apple production in the Okanagan has shifted from yield to yield plus quality as the desirable response. Nitrogen was assumed to be an important factor affecting yield and quality of apples. There was a trend toward using grass as an understory cover crop (Mason 1964), and therefore nitrogen studies emphasized the interaction between nitrogen fertilizer and understory management on apple yield and quality. Several studies of this type showed almost no difference in response to a wide range of nitrogen treatments and a moderate range of cultivation treatments (Mason 1969b). Mason speculated further that nitrogen fertilizer may not be necessary in orchards of high initial fertility with a grass cover between the rows and may be required in only small quantities for today's market requirements of fruit color. Concentrations of nitrogen in leaf tissue (Mason 1964) do suggest that the orchards were on soils with adequate nitrogen levels, and consequently that the grass understory would be beneficial in limiting nitrogen supply to apple trees in the fall. Therefore, the quality of the apples, as determined by skin color of the fruit and by firmness, would be improved (Mason 1969a; Neilsen et al. 1984). Although lower nitrogen supply in the fall is desirable for maintaining apple quality under present marketing criteria (colorful and not too big), an adequate supply of nitrogen in the spring appears to be required for adequate yield (Mason 1964). Neilsen and Hogue (1985) recommended that control of understory vegetation early in the season would be necessary to maintain an adequate, well-timed nitrogen supply for optimum marketable yields of apples, particularly because previous work (Neilsen et al. 1984) showed that apple trees appeared to be more responsive to what was done to the soil between the rows than to nitrogen application in the spring.

Recently, attention has been directed toward the effect of irrigation frequency on nutrient uptake of apple trees. Neilsen and Stevenson (1986) found that in 1 year out of 4, the concentration of nitrogen in the leaves of apple (Summerland Red McIntosh) trees was higher with daily irrigation than with twice-weekly irrigation. They concluded that nitrogen nutrition (as well as that of magnesium and zinc) could be improved by high-frequency irrigation. This effect would be an additional benefit of trickle irrigation, which tends to require frequent water applications. It would be useful to know why the increased nitrogen concentration occurred.

Vegetables and fruit crops other than apples are grown in the Okanagan under intensive irrigation practices, but research publications on them related to nitrogen are largely absent. Only a study by Molnar (1961) was found. His study, which of necessity was short-term, examined the effect of nitrogen on peach tree growth but did not include yield measurements. Nitrogen applications were shown to extend the length of vegetative growth and to increase nitrate nitrogen and the total amount of nitrogen, as well as the green and yellow pigment content of leaves, despite the plot area having had a history of substantial manure applications plus nitrogen at 45 kg/ha per year as fertilizer.

One general observation about all the reports discussed is that analysis of nitrogen directly in the soil was omitted. This limits the interpretation of the results. It should be remembered also that all the studies were conducted under irrigated conditions, and so the possibility of nitrogen application by the irrigation water (water quality) should not be ignored. The duration of the studies related to understory management should be considered in the interpretation. Since apples are produced for a long period of time in a given orchard, a stable nutrient equilibrium may not have been fully established in the soil plant system, resulting in differences between short- and long-term interpretations. The studies recorded with a grass understory did not indicate whether the nitrogen content of grass was determined.

The high intensity of agricultural activity and a growing population have put considerable pressure on the quantity and quality of water in the Okanagan Basin (Canada - British Columbia Consultative Board 1974). The effects of nitrogen, from both agricultural and urban activity, on water quality is an area of concern. The efficient use of nitrogen for crop production will be required not only for economic crop production (agricultural perspective) but also for minimizing the impact of increased nitrogen on general water quality (environmental perspective).

One characteristic of research on orchard crops is that both long- and short-term implications must be considered. As a result, a current study is measuring the long-term effects of understory management where short-term effects were reported earlier (Neilsen et al. 1984; Neilsen and Hogue 1985). Cultivars of apples grown also change with time, resulting in a need for further research, as with Spartan apple trees, for example. A trial in its third year is examining rate of nitrogen (50 and 100 kg/ha), applied at two times (spring and fall), and in two forms (urea and NH_4NO_3) on Spartan apple trees. Another trial in its fifth year is examining three nitrogen rates with and without phosphorus and potassium and three nitrogen rates with several soil-managed treatments.

Trickle irrigation is being evaluated at this time. Tests are being conducted in which nitrogen fertilizer is applied through this system. With this approach, timing of nitrogen application is easy, and costs of nitrogen applications can be reduced.

In response to a concern about the water quality of lakes in the Okanagan Valley, several studies have been initiated. Lysimeter studies are currently in progress at Summerland Research Station to measure nitrogen leaching as a result of irrigation. An experiment on Red Delicious and McIntosh apples and on cherries, peaches, and grapes is examining the application of secondary-treated effluent by trickle irrigation. This type of irrigation is being compared with trickle irrigation using well water with three rates of nitrogen applied in the spring.

Humidic nitrogen management unit

By 1963, general fertilizer recommendations for this management unit, which essentially comprises the Coastal area, appear to have been established on the basis of numerous fertilizer response trials and general observations (Nelson 1963). At about that time, more site-specific fertilizer recommendations were needed, and a soil-test system was gradually developed. However, emphasis was directed toward the relatively immobile nutrients (e.g., phosphorus, potassium, magnesium, and the micronutrient boron) and as a result a soil test for nitrogen has received only limited attention. A general recommendation based on past observations and modified according to soil type and previous management, particularly manure application, is still largely used even though the provincial soil test laboratory routinely includes nitrate analysis of soil samples.

Although numerous fertilizer response trials that include nitrogen have been conducted, details of exactly what was done are not available because results are published only in brief progress and annual reports (Canada Department of Agriculture 1947, 1955, 1957, 1963). Yield response was the primary criterion on which the results were interpreted. Negligible plant nitrogen uptake and soil nitrogen measurements were made and therefore limited understanding of the reasons for these results.

During this time, research on nitrogen at the University of British Columbia was geared toward an understanding of the role of microorganisms on nitrogen transformations. Studies on nitrifiers (Sparks 1928), nitrogen fixers (West 1937), and actinomycetes (Gilmour 1945) contributed to a general understanding of nitrogen processes.

Many management factors can influence the efficiency of fertilizer nitrogen use. In forage production, fertilizer can be applied several times during the growing season. Studies have shown that split applications of nitrogen on south coastal soils produce little or no differences in total yield but tend to result in a redistribution of growth during the growing season (Gardner et al. 1960; Maas et al. 1962; Bomke and Bertrand 1983). The study of Gardner et al. (1960) showed that Ladino clover in a mixture of grass could reduce the fertilizer nitrogen requirement in a nitrogen-deficient soil. Bomke and Bertrand (1983) observed a small (8%) yield advantage of ammonium nitrate over urea in only 1 out of 3 years of their study. A spring application of nitrogen was shown to affect yield of grass through the growing season, with variable interactions with sulfur in the spring compared with the fall (Kowalenko 1984d). Soil nitrogen analyses were not recorded in any of the reports, making it difficult to determine the reason for the observed results.

Management factors can also influence the efficiency of nitrogen uptake by forage corn and hence the forage quality. Fairey (1982) reported that the nitrogen content of stover and whole plants was not greatly influenced by population density but was closely related to maturity of hybrids at harvest. A subsequent report (Fairey 1983) stated that whole-plant nitrogen content increased progressively as planting date was delayed. However, the rate of increase declined as the harvest date was delayed. In addition, whole-plant nitrogen content decreased for each date of planting as the date of harvest was delayed. Similar trends were observed for the nitrogen content of stover, except that the increases in nitrogen content resulting from delayed planting occurred at the same rate for each harvest-date treatment. Nitrogen was not a treatment factor for either trial; neither soil nitrogen status nor nitrogen fertilization information was provided. The productivity and quality of perennial ryegrass was shown to respond to combinations of cutting frequency and total rate of nitrogen applied (Fairey 1985). Only limited combinations were examined (four cuts with nitrogen at 300 kg/ha and eight cuts at 450 kg/ha), and residual soil nitrogen was not determined. In a study of the accumulation of nitrogen in corn at three locations in 1 year, Loewen (1979) found that the most rapid accumulation by the plant occurred 40-70 days after planting, which would coincide with the month of July. Accumulated nitrogen (excluding roots) ranged from 129 to 167 kg/ha. These studies show the complexity of nitrogen in a forage - soil system and the interaction of many factors in the final result.

Nitrogen increases the production of cereal grain, but lodging becomes a serious problem under coastal soil and weather conditions. Nitrogen application is often restricted, so that crop losses resulting from lodging are reduced. The objective then is to fertilize with nitrogen to a level where high yields are obtained without increasing the risk of lodging. Johnson (1968) was able to produce maximum yield without lodging using Gaines wheat with nitrogen at 112-157 kg/ha. It was suggested that Gaines wheat had relatively high inherent lodging resistance. This study showed that the variety of wheat can influence the effectiveness of nitrogen fertilization of wheat. Research reports examining this interaction under conditions in south coastal British Columbia are not available.

Little information has been published on the effect of nitrogen on vegetable production in south coastal British Columbia. Freeman (1950) showed that nitrogen had a detrimental effect on yield of carrot roots. Nitrogen apparently increased the growth of the tops of the plants but did not proportionately increase the roots. Nitrogen was also shown to increase the carotene content of carrots (Freeman 1951). Maas (1963, 1968) observed that nitrogen application could increase yield of potatoes but tended to decrease the specific gravity. The rate of release of nitrate nitrogen, as measured in growth chamber and laboratory tests in one of these trials, was low in the nitrogen-responsive organic soil (Maas 1968).

Organic soils (peats) are frequently used for highbush blueberry production. Herath (1967) showed that waterlogging a peat soil resulted in nitrogen deficiency for blueberry plant growth, which produced shorter, more compact plants from reduced shoot growth, yellowing, premature leaf aging, and low nitrogen levels in the leaves. Analysis of nitrogen in the leaves suggested that blueberries preferentially absorbed ammonium over nitrate nitrogen. Nitrate at levels exceeding 22 kg/ha resulted in nitrate toxicity as shown by severe leaf burn.

Maas (1967) showed that the total nitrogen content of the surface layer of a Vancouver Island peat differed, depending on the substrata. Sedge substrata tended to produce sphagnum peat of higher nitrogen content than sphagnum substrata.

Kowalenko (1981a) found that optimum yield and berry size response by raspberries occurred when nitrogen was applied at a rate of 134 kg/ha in a field trial in the Abbotsford area. The highest nitrogen treatment rate was 268 kg/ha. Concentrations of nitrogen in leaf tissue were influenced by nitrogen applications, but since there was a gradual decline in the leaves of both old and new canes, it was concluded that nitrogen fertilizer recommendations based on analysis of leaf tissue would be difficult to implement (Kowalenko 1981b).

Limited data on field plots (Kowalenko and Maas 1982a, 1982b) and orchard surveys (Kowalenko 1984a, 1984c), which complimented data in the literature, have been used as the basis for a method of leaf tissue analysis for determining nitrogen (and other fertilizer) requirements of filberts in British Columbia (Kowalenko 1984b). Nitrogen appears to strongly influence the yield of filberts.

Agricultural production in the lower Fraser Valley is intense. Manure production from livestock under this intensive management is high, relative to the limited land base available for application. If 1981 census figures for number of livestock for the Mainland region are multiplied by an approximate amount of nitrogen voided per year, animals would produce nitrogen at a rate of 11 292 600 kg/year (Table 5). Assuming no losses and calculating on the basis of 81 099 ha of improved farmland for that census region, nitrogen production would be equivalent to 139 kg/ha per year. Since nitrogen in manure is a valuable resource but also a serious potential environmental pollutant, research has increasingly shifted to this aspect in the Lower Mainland (Bomke and Lavkulich 1975; Bulley and Holbek 1978; Holbek 1978; Maynard and Bomke 1980). A solution to the manure problem was also attempted using a simulation model (Bulley and Cappalaere 1978; Cappalaere 1978), where

Table 5. Number of livestock in south coast mainland of British Columbia according to 1981 census* and the calculated manure nitrogen voided per year.

	Number	N voided per animal† (g/day)	N voided (kg/day)	N voided per year (kg/300 days)
Cattle	159 027	120	19 083	5 724 900
Hens & chickens	7 991 733	1.45	11 588	3 476 400
Turkeys	595 585	1.0	596	178 800
Goats	3 270	20	65	19 500
Horses	7 804	122	952	285 600
Pigs	158 937	32	5 086	1 525 800
Sheep	12 985	20	260	78 000
Rabbits	11 681	1.0	12	3 600
Total				11 292 600

*Adapted from Macey 1982.
†Adapted from Barber 1979.

management of manure to minimize nitrogen losses was the major goal. This model is being refined to develop guidelines for the management of manure. The simulation model is based on rates of various nitrogen processes (mineralization, nitrification, denitrification) and water movement in soil. Because of the paucity of information on nitrogen processes in local soils that can be used for modeling purposes (Harris and Woods 1935; Gardiner et al. 1960; Derics 1963; Basaraba 1964a, 1964b; Kowalenko and Lowe 1975, 1978; Phillips 1976; Hinds and Lowe 1980; Guthrie and Bomke 1980, 1981; Guthrie 1981; Lowe and Hinds 1983), data from the literature have been extrapolated for estimating rates of nitrogen. Of these studies, only those of Harris and Woods (1935) and Guthrie and Bomke (1980) were done in the field.

A recently completed study on the effect of rate and placement of anaerobically stored swine slurry on silage corn production showed the following: the slurry contributed yield increases that were up to 18% beyond the effects of starter nitrogen, phorphorus, and potassium at soil test recommended rates; injection of manure to a depth of 30 cm resulted in greater recovery as soil nitrogen in the fall than did surface application; and over-the-winter loss of residual nitrate was substantial (Khan 1986). The field study was conducted over 3 years and included considerable monitoring of nitrogen in the soil.

The nitrate concentration of groundwater has been extensively measured in the lower Fraser Valley, but little has been published. A number of areas in the lower Fraser Valley have groundwater with relatively high nitrate concentrations (Kohut 1985; Leibscher 1985). Apparently, areas of concern

Fig. 2. Soil test interpretation zones in British Columbia.

include Langley - east Surrey, south Abbotsford, Matsqui, and Seabird Island. Suspected sources of this nitrate include agricultural activities and sewage effluent. Manure stockpiling for poultry, mink, and pig operations are of particular concern because of the potentially large and concentrated source of nitrate. However, general fertilizer spreading and nitrate contamination of surface water are also a concern.

At the University of British Columbia a project on nitrogen for the production of sweet corn is progressing in two parts: the usefulness of spring NO_3 and NH_4 soil analysis is being evaluated for application on corn during the early part of the growing season; and the relationship between the nitrogen supplying power and various soil properties is being examined.

The Soils Branch of the British Columbia Ministry of Agriculture and Food is continuing the refinement and implementation of manure management guidelines. Researchers are using the manure simulation model that was recently formulated.

A private laboratory is conducting exploration of the relative cost of various soil analyses that may eventually be considered as an objective basis for nitrogen fertilizer recommendations.

At Agassiz Research Station, several studies on nitrogen are in progress. Nitrogen transformations and transport have been monitored under fallow conditions where applications were made in the spring and fall. Both tracer (^{15}N) and nontracer methods were used. Fieldwork has been completed, and laboratory and statistical analyses are in progress. The effect of nitrogen on broccoli production is being examined. The study includes a comparison of the response and uptake of sweet corn and broccoli to nitrogen. A cooperative study between the British Columbia Ministry of Agriculture and Food and the University of British Columbia is examining "T-sum" for timing the application of nitrogen on grass in the early spring. T-sum is the average of the daily maximum and minimum temperatures (degrees C) above zero accumulated from 1 January. The system was developed in Great Britain and Holland. A soil test monitoring project is also in progress. Results of nitrate nitrogen analysis of fall and spring samples will be examined on six fields over several years. Replicate analysis of each field will allow the determination of field variability and the evaluation of changes over the winter.

OUTLINE OF THE CURRENT SYSTEM OF RECOMMENDATION

The range and distribution of agriculture has resulted in a complex system for the establishment of soil tests and recommendations for British Columbia. The provincial soil-testing laboratory has designated a number of zones to facilitate interpretations. Several zones are currently used for recommendations on nitrogen and other nutrients (Fig. 2). The recommendations are further modified by considering the type of crop that is grown. For simplicity, 12 crop categories used for nitrogen recommendations are illustrated (Table 6), but a much more detailed system has been developed for specific crops and for perennial crops of various ages. Plant-oriented

Table 6. Soil testing laboratory recommendations for maximum nitrogen applications on selected categories of crops in interpretation zones of British Columbia.

Crop category	Zone*	Rate of N (kg/ha)
Vegetables	All	140
Ornamentals	All	80
Lawns and gardens	All	60
Fruit trees	All	120
Small fruits	All	50
Grapes	All	80
Cereals	1, 2	90
	3, 4, 5, 5.01, 6	70
Corn (silage)	1, 2	40 + 75
	3, 4, 5, 5.01, 6	120
Grass (established)	1, 2, 3, 4, 5.01	55(after each cut)
	5	80 + 55
	6	90
Grass - legume	1, 2, 3, 4, 5.01	55(after each cut)
	5	80 + 55
	6	55
Alfalfa (established)	1, 2, 3, 4, 5.01	20
	5	33
	6	20
Range (tame grass)	All	40
	All	25

*1 = Vancouver Island, 2 = Lower Mainland, 3 = Boundary, North and South Okanagan, 4 = Southeastern British Columbia, 5.01 = Quesnel, 5 = North Central British Columbia, 6 = Peace River.

Table 7. British Columbia Soil Test Laboratory ratings of surface soil nitrate values.

Soil NO_3-N (µg/mL)	Rating*
Below 11	Very low
11-20	Low
21-40	Low medium
41-50	Medium
51-60	High medium
61-100	High
More than 100	Very high

Table 8. Recommmended adjustments by British Columbia Soil Testing Laboratory to nitrogen fertilizer rates on tree fruit according to nitrogen concentrations (ppm) present in leaves sampled in late June or July.

Type	Age (yrs)	N application increased by		Application rate not changed	N application decreased by	
		50%	20%		20%	50%
Apples						
Newton & Delicious	<10	<1.80	1.80-2.09	2.10-2.49	2.50-2.69	>2.69
	>11	<1.80	1.80-2.09	2.10-2.19	2.80-2.99	>2.99
Golden Delicious	Mature	<1.80	1.50-1.79	1.80-1.79	2.00-2.29	>2.29
McIntosh	<10	<1.60	1.60-1.89	1.90-2.29	2.30-2.49	>2.49
	>11	<1.60	1.60-1.89	1.90-2.59	2.60-2.79	>2.79
Spartan	<10	<1.50	1.50-1.79	1.80-2.19	2.20-2.39	>2.39
	>11	<1.50	1.50-1.79	1.80-2.49	2.50-2.69	>2.69
Winesap		<1.60	1.60-1.89	1.90-2.19	2.20-2.49	>2.49
Others		<1.60	1.60-1.89	1.90-2.29	2.30-2.59	>2.59
Cherries	<10	<1.60	1.60-1.89	1.90-2.69	2.70-3.29	>3.29
	>11	<1.60	1.60-1.89	1.90-2.99	3.00-3.59	>3.59
Pears	<10	<1.60	1.60-1.89	1.90-2.29	2.30-2.49	>2.49
	>11	<1.60	1.60-1.89	1.90-2.49	2.50-2.69	>2.69
Prunes	<10	<1.60	1.60-1.89	1.90-2.49	2.50-2.99	>2.99
	>11	<1.60	1.60-1.89	1.90-2.79	2.80-3.19	>3.19
Peaches	<10	<2.00	2.00-2.59	2.60-3.19	3.20-3.79	>3.19
	>11	<2.00	2.00-2.59	2.60-3.49	3.50-4.10	>4.10
Apricots	<10	<2.00	2.00-2.59	2.60-3.29	3.30-3.79	>3.79
	>11	<2.00	2.00-2.59	2.60-3.49	3.50-4.10	>4.10

Table 9. Recommended adjustments by British Columbia Soil Test Laboratory to nitrogen fertilizer rates on grapes according to nitrogen concentrations (ppm) in leaf petioles sampled at bloom time.

	Guide rate*	N application increased by		Application rate not changed	N application decreased by		No N needed
		50%	20%		20%	50%	
Vinifera labrusca and hybrids							
low vigor	<0.40	0.40-0.69	0.70-0.99	1.00-1.70	1.71-1.95	1.96-2.20	>2.20
med vigor	<0.40	0.40-0.69	0.70-0.90	0.91-1.60	1.61-2.00	2.01-2.49	>2.49
high vigor	<0.30	0.30-0.54	0.55-0.79	0.80-1.60	1.61-2.00	2.01-2.49	>2.49
Vinifera vinifera							
low vigor	<0.91	0.91-1.19	1.20-1.49	1.50-3.00	3.01-3.25	3.26-3.99	>3.99
med vigor	<1.40	1.40-1.64	1.65-1.90	1.91-2.70	2.71-3.00	3.01-3.69	>3.69
high vigor	<1.00	1.00-1.24	1.25-1.49	1.50-3.00	3.01-3.40	3.41-3.99	>3.99

*See Grape Production Guide 1986, British Columbia Ministry of Agriculture and Food, Victoria, B.C., for general recommendations on nitrogen application rates.

Table 10. Comparison of the distribution of fertilizer nitrogen application rates with British Columbia Soil Test Laboratory maximum recommended rates calculated from 1981 agricultural census for British Columbia.

Area	Nitrogen fertilizer use (kg/ha)	Maximum general recommended rate (kg/ha)
Coastal	120	144
(Lower Mainland)	(129)	(140)
Okanagan	79	76
Peace River	31	56
Interior	39	79
Total	53	

research and the relatively high rainfall in many areas have resulted in nitrogen recommendations that are general rather than specific. Nitrate has been included in soil analysis for a number of years, and more recently it has been used to modify the general recommendations. The soil nitrate ranges are given a rating that is independent of the crop (Table 7). In many cases only a general nitrogen recommendation is given, and a precautionary comment is made if the soil nitrate value is high. Where soil nitrate values are used, recommendations are made by adjusting the maximum nitrogen recommendation downward by subtracting twice the soil nitrate value rounded to the nearest 10. This system has particular application to the Peace River and Interior areas, but must be used with extreme caution in other circumstances. Caution is required because usually only the surface 15 cm is sampled, the samples are not always immediately dried, and sampling time is critical, especially in the wetter areas.

Nitrogen recommendations are also made for fruit trees, grapes, and filberts. For fruit trees, leaf analysis is used, and recommendations are adjusted according to type and age of the tree (Table 8). In the case of apples, each cultivar requires its own recommendations. At present, leaf petiole analysis is used for grapes. Recommendations take into consideration the species and their vigor (Table 9). Consideration is being given to converting from petiole to leaf analysis. The target concentration of nitrogen for filbert leaves is not differentiated by age or cultivar of the tree. The target concentration was, however, developed for mature trees. In all cases, the recommendations for fruit trees, grapes, and filberts are mainly upward or downward adjustments to the growers' application rates, but general recommendation rates are available in various guides.

The general approach to recommendations based on soil analysis probably reflects the limited soil-based information that is available as well as the wet weather, particularly in the winter. More detailed recommendations for tree fruits and grapes by analysis of leaf tissue probably reflect the larger base of research information and greater confidence in extrapolating data on plant analysis (as compared with soil research information) from one location to another.

ASSESSMENT OF FERTILIZER NITROGEN USE

An estimate of the distribution of the rate of nitrogen used in the province is difficult without an extensive survey of individual farms. Census data from 1981 (Macey 1982) do provide information on the rate of fertilizer use for each district in the province but do not show the proportion of nitrogen used. A calculation using detailed documentation of sales from 1975 to 1977 (British Columbia Ministry of Agriculture and Food 1979) shows that 20% of the fertilizer used in the province was nitrogen. By applying this proportion to the census data, the rate of nitrogen use was calculated for the various areas (Table 10). Also, by using a maximum rate of nitrogen recommended by the soil test laboratory and the area of each crop identified in the census, a maximum recommended rate for each area was calculated.

A comparison of these two sets of figures shows that both the Coastal and Okanagan areas are using almost the maximum general recommended rate, whereas the Peace River and Interior areas use considerably less than the maximum (Table 10). This difference probably reflects the intensity of agriculture in the various regions. It should be noted that a previous calculation (Table 5) showed that sufficient nitrogen was voided from livestock in the Lower Mainland to apply it at a rate of 139 kg/ha of improved farmland in the area. This finding suggests that even if nitrogen loss of manure averaged 50% by the time it is spread on the land, considerably more nitrogen than the maximum recommended is applied. Large amounts of feed such as alfalfa hay and grain are imported into the Lower Mainland for intensive management of livestock. Livestock are much less concentrated in the Okanagan than in the Lower Mainland, and therefore the contribution of nitrogen is lower (nitrogen voided at 44 kg/ha of improved farmland). Also, in the Okanagan, sewage resulting from urban expansion and the acidifying effect of nitrogen fertilizers on orchard soils are causing concern.

CONCLUSIONS

Although the calculations used to assess nitrogen fertilizer use in British Columbia are approximate, the relative distribution should give an accurate picture of the current situation. It is assumed that the pattern of use has not changed much since 1981. The figures do show that in general, the intensively farmed areas (Coastal and Okanagan) are reaching or exceeding maximum recommended rates, whereas less intensively farmed areas (Interior and Peace River) are falling below the maximum general recommended rates. A review of published research shows that current recommendations are based on plant response, and little information on soil analysis data is available. The use of soil analysis for nitrogen recommendation can be considered only tentative, because of the limited findings available on soil-oriented research. Analysis of the leaf tissue of tree fruits, grapes, and filberts is well accepted, but little information is available for the interpretation of soil analysis. Nitrogen fertilization has been shown to contribute to accelerated acidification of Okanagan soils. Efficient nitrogen fertilization is needed to limit acidification.

Nitrogen applications in the Coastal and Okanagan areas are at a level that may result in significant problems because of excessive use, such as diminishing returns on investments and environmental problems. The high concentration of livestock, particularly in the Lower Mainland, will require nitrogen from manure to be used as efficiently as possible. Otherwise, manure may be viewed as a disposal problem rather than a valuable nutrient source. On the other hand, farmers in the Interior and Peace River areas may not be fully exploiting the potential economic advantages of increased nitrogen fertilizer. Research on soil-based nitrogen, which can be used to provide an effective extension program to promote efficient nitrogen use, is limited in all regions of the province. Without adequate research, specific recommendations for sites with various management histories and various soil characteristics will inspire only limited confidence. Research on nitrogen needs a different direction and orientation for the varied climate and agriculture of British Columbia. At least as much research will be required to promote a limit on nitrogen application as will be required to encourage increased use.

Little research has been published on biological nitrogen fixation, particularly beyond the Peace River area. Alfalfa is a significant crop in the Interior and Okanagan, and the efficiency of the utilization of nitrogen fixation has not been assessed. Research on this aspect of nitrogen should be encouraged, particularly for extensive farm operations. However, the possibility of increasing the use of the nitrogen applied in the Coastal area should also be seriously considered.

REFERENCES

Agriculture Canada. 1971. Roundup of rangeland fertilization in British Columbia, Alberta, and Oregon at Kamloops, B.C., 23 and 24 June 1971. Scientific Information Section, Research Branch, Agriculture Canada, Ottawa, Ont.

Ashby, D.L. 1969. Controlled release of magnesium, zinc, boron and nitrogen from polyethylene capsules. Can. J. Plant Sci. 49:555-566.

Barber, E.M. 1979. Canada animal manure management guide. Agric. Can. Publ. 1534:19.

Basaraba, J. 1964a. Influence of vegetable tannins on nitrification in soil. Plant Soil 21:8-16.

Basaraba, J. 1964b. Mineralization of urea-formaldehyde compounds at different pH levels and temperatures. Can. J. Soil Sci. 44:131-136.

Beaton, J.D.; Warren, R.A.J.; Hubbard, W.A. 1960. Nitrate supplying power of eight grassland soils of the Kamloops, B.C., area and correlation with range forage production. Can. J. Soil Sci. 40:63-70.

Bentley, C.F., ed. 1979. Photographs and descriptions of some Canadian soils. Vol. 4, Publication B79-1, Extension Series. University of Alberta, Edmonton, Alta., pp. 30-31.

Bomke, A.A.; Bertrand, R.A. 1983. Response of an orchardgrass-perennial ryegrass sward to rate and method of urea and ammonium nitrate application. Can. J. Soil Sci. 63:719-725.

Bomke, A.A.; Lavkulich, L.M. 1975. Composition of poultry manure and effect of heavy application on soil chemical properties and plant nutrition, British Columbia, Canada. In Managing livestock wastes. Proceedings third international symposium on livestock wastes, Proc-275. American Society of Agricultural Engineers, St. Joseph, Mich., pp. 614-617.

British Columbia Ministry of Agriculture and Food. 1979. British Columbia 1978 agriculture statistics yearbook. British Columbia Ministry of Agriculture and Food, Victoria, B.C., p. 32.

Broersma, K.; Kline, P. 1982. Nitrate accumulation in meadow foxtail, reed canarygrass and timothy fertilized with nitrogen. Canadex--Soils 543.127.

Broersma, K.; van Ryswyk, A.L. 1979. Magnesium deficiencies observed in forage corn varieties. Can. J. Plant Sci. 59:541-544.

Bulley, N.R.; Cappalaere, B. 1978. A dynamic simulation model of nitrogen movement on livestock farms. Pap. 7-211. Canadian Society of Agricicultural Engineering, annual meeting, Regina, Sask. 20 pp.

Bulley, N.R.; Holbek, N.E. 1978. Manure loading rates on farmland. Canadex (Farm Manure) 538.

Canada - British Columbia Consultative Board. 1974. Summary report of the consultative board including the comprehensive framework plan. British Columbia Water Resources Services, Victoria, B.C.

Canada Department of Agriculture. 1947. Dominion Experimental Farm, Agassiz, British Columbia. Progress Report, 1936-1947. Canada Department of Agriculture, Ottawa, Ont., pp. 22-29.

Canada Department of Agriculture. 1955. Annual Report of the Dominion Experimental Farm, Agassiz, B.C. Canada Department of Agriculture, Ottawa, Ont., pp. 134-145.

Canada Department of Agriculture. 1957. Dominion Experimental Farm, Agassiz, B.C. Progress Report, 1953-1957. Canada Department of Agriculture, Ottawa, Ont., pp. 22-28.

Canada Department of Agriculture. 1963. Research Report, 1961-1963. Experimental Farm, Agassiz, B.C. Canada Department of Agriculture, Ottawa, Ont., pp. 10-12.

Cappalaere, B. 1978. Modelling subsurface movement of manurial nitrogen in a shallow unconfined aquifer. M.A.Sc. thesis, University of British Columbia, Vancouver, B.C.

Central Interior Forage Extension Committee. 1981. Management and improvement of organic wetlands in the interior of British Columbia. Publication 81-3. British Columbia Ministry of Agriculture and Food, Victoria, B.C., pp. 7-8.

Chilton, R.R.H. 1981. A summary of climatic regimes of British Columbia. Assessment and Planning Division, Air Studies Branch, British Columbia Ministry of Environment, Victoria, B.C. 46 pp.

Derics, I.A. 1963. The effect of lime on mineralization of organic nitrogen in the three Fraser Valley soils. Unpublished B.Sc.(Agric.) thesis. University of British Columbia, Vancouver, B.C.

Doggart, M.; Tingle, J.; Kline, R.; Bertrand, R.; Bomke, A.; Wessel, J.; Broersma, K. 1983. Fertilizer-crop correlation study. Technical Report I: Site characterization, climate, dry matter yields and nutrient response tables. Feed Freight Adjustment Fund Agreement and British Columbia Ministry of Agriculture and Food, Victoria, B.C. 99 pp.

Fairey, N.A. 1982. Influence of population density and hybrid maturity on productivity and quality of forage maize. Can. J. Plant Sci. 62:427-434.

Fairey, N.A. 1983. Yield, quality and development of forage maize as influenced by dates of planting and harvesting. Can. J. Plant Sci. 63: 157-168.

Fairey, N.A. 1985. Productivity, quality and persistence of perennial ryegrass as influenced by cutting/fertility management and ploidy. Can. J. Plant Sci. 65:565-571.

Freeman, J.A. 1950. The effect of nitrogen, phosphorus, potash and chloride on the yield and top-root ratio of carrots (Daucas carota). Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Freeman, J.A.; Harris, G.H. 1951. The effect of nitrogen, phosphorus, potassium and chlorine on the carotene content of the carrot. Sci. Agric. 31:207-211.

Freyman, S.; van Ryswyk, A.L. 1969. Effect of fertilizer on pinegrass in southern British Columbia. J. Range Manage. 22:390-395.

Gardner, E.H.; Derics, I.A.; Basaraba, J. 1965. Mineralization of nitrogen in some Fraser Valley soils as affected by liming. Can. J. Soil Sci. 45:355-356.

Gardner, E.H.; Jackson, T.L.; Webster, G.R.; Turley, R.H. 1960. Some effects of fertilization on the yield, botanical and chemical composition of irrigated grass and grass-clover pasture swards. Can. J. Plant Sci. 40:546-562.

Gilmour, C.G. 1945. The influence of nitrogen and carbon sources on the metabolism of the actinomycetes. Unpublished M.S.A. thesis, University of British Columbia, Vancouver, B.C.

Gough, N.A. 1984. Annual report to the soils branch. British Columbia Ministry of Agriculture and Food, Victoria, B.C., pp. 10-11.

Guthrie, T.F. 1981. Evaluation of the nitrifiction inhibitors N-serve and ATC with urea fertilizer. Ph.D. thesis, University of British Columbia, Vancouver, B.C.

Guthrie, T.F.; Bomke, A.A. 1980. Nitrification inhibition by N-serve and ATC in soils of varying texture. Soil Sci. Soc. Am. J. 44:314-320.

Guthrie, T.F.; Bomke, A.A. 1981. Effects of low temperature and nitrification inhibitors on urea hydrolysis. Can. J. Soil Sci. 61:529-532.

Hall, K.M. 1971. Responses to fertilizer nitrogen of rangeland at various elevations in the southern interior of British Columbia. M.Sc. thesis, University of British Columbia, Vancouver, B.C.

Harris, G.H.; Woods, J.J. 1935. Raspberry nutrition. I. Seasonal variation of plant nutrients in raspberry plantings under different cultural treatments. Sci. Agric. 15:525-534.

Hennig, A.M.F.; Rice, W.A. 1977. Effects of date of sod breaking on nitrogen requirements and yield of barley following fescue in rotation. Can. J. Soil Sci. 57:477-485.

Herath, H.M.E. 1967. Some effects of water table, pH, and ammonium and nitrate nitrogen upon the growth and composition of highbush blueberry. Unpublished M.S.A. thesis, University of British Columbia, Vancouver, B.C.

Hilliard, C.R. 1983. Nitrogen: Uptake by corn and movement in soil as a function of fertilizer application rate. B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Hinds, A.A.; Lowe, L.E. 1980. Distribution of carbon, nitrogen, sulphur and phosphorus in particle-size separates from gleysolic soils. Can. J. Soil Sci. 60:783-786.

Holbek, N.E. 1978. Two dairy waste handling systems: A comparison of nitrogen balances. M.Sc. thesis, University of British Columbia, Vancouver, B.C.

Hoyt, P.B.; Hennig, A.M.F. 1971. Effect of alfalfa and grasses on yield of subsequent wheat crops and some chemical properties of a Gray Wooded soil. Can. J. Soil Sci. 51:177-183.

Hoyt, P.B.; Hennig, A.M.F. 1982. Soil acidification by fertilizer and longevity of lime applications in the Peace River region. Can. J. Soil Sci. 62:155-163.

Hoyt, P.B.; Leitch, R.H. 1983. Effects of forage legume species on soil moisture, nitrogen, and yield of succeeding barley crops. Can. J. Soil Sci. 63:125-136.

Hoyt, P.B.: Neilsen, G.H. 1985. Effects of soil pH and associated cations on growth of apple trees planted in old orchard soil. Plant Soil 86:395-401.

Hubbard, W.A.; Mason, J.L. 1967. Residual effects of ammonium nitrate and ammonium phosphate on some native ranges of British Columbia. J. Range Manage. 20:1-5.

Johnson, H.S. 1968. Effect of nitrogen fertilizers on yield, yield components and other agronomic features of Gaines wheat. Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Khan, M.R. 1986. Effects of rates and method of swine slurry application on crop nitrogen uptake and nitrogen distribution in the soil. Ph.D. thesis, University of British Columbia, Vancouver, B.C.

Kline, P.; Broersma, K. 1983. The yield, nitrogen and nitrate content of reed canarygrass, meadow foxtail and timothy fertilized with nitrogen. Can. J. Plant Sci. 63:943-950.

Kowalenko, C.G. 1981a. Response of raspberries to soil and boron applications. Commun. Soil Sci. Plant Anal. 12:1151-1162.

Kowalenko, C.G. 1981b. The effect of nitrogen and boron soil applications on raspberry leaf N, B and Mn concentrations and on selected soil analyses. Commun. Soil Sci. Plant Anal. 12:1163-1179.

Kowalenko, C.G. 1984a. Derivation of nutrient requirements of filberts using orchard surveys. Can. J. Soil Sci. 64:115-123.

Kowalenko, C.G. 1984b. Determining fertilizer requirements of filberts. Agric. Can. Res. Br. Tech. Bull. 1984-8E. 6 pp.

Kowalenko, C.G. 1984c. The necessity of washing filbert leaves for macro- and micronutrient considerations. Can. J. Soil Sci. 64:147-149.

Kowalenko, C.G. 1984d. Yield response of forage grass to sulphur applications on Fraser Valley soils. In Sulphur-84. Proceedings sulphur-84 conference. Sulphur Development Institute of Canada, Calgary, Alta., pp. 823-827.

Kowalenko, C.G.; Lowe, L.E. 1975. Mineralization of sulfur from four soils and its relationship to soil carbon, nitrogen and phosphorus. Can. J. Soil Sci. 55:9-14.

Kowalenko, C.G.; Lowe, L.E. 1978. Effects of added nitrogen on the net mineralization of soil sulphur from two soils during incubation. Can. J. Soil Sci. 58:99-101.

Kowalenko, C.G.; Maas, E.F. 1982a. Some effects of fertilizer and lime application to filbert orchards in the Fraser Valley of British Columbia. Can. J. Soil Sci. 62:71-77.

Kowalenko, C.G.; Maas, E.F. 1982b. Seasonal effect on leaf nutrient concentrations of filbert. Can. J. Soil Sci. 62:209-211.

Le Pine, D.J. 1975. A comparison of urea and ammonium intake as a source of nitrogen in central British Columbia. Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Loewen, S. 1979. The accumulation of nitrogen by corn in the Fraser Valley. Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Lowe, L.E.; Hinds, A.A. 1983. The mineralization of nitrogen and sulphur from particle-size separates of gleysolic soils. Can. J. Soil Sci. 63:761-766.

Maas, E.F. 1963. The effect of seed spacing and nitrogen levels on the size of Netted Gem potatoes. Am. Potato J. 40:133-136.

Maas, E.F. 1967. The chemical composition of Sphagnum species and the influence of drainage on its location. Soil Sci. Soc. Am. Proc. 31:577.

Maas, E.F. 1968. Nitrogen deficiency of potatoes in organic soils. Am. Potato J. 45:378-382.

Maas, E.F.; Webster, G.R.; Gardner, E.H.; Turley, R.H. 1962. Yield response, residual nitrogen and clover content of an irrigated grass-clover pasture as affected by various rates and frequencies of nitrogen application. Agron. J. 54:212-214.

Macey, C. 1982. Census of agriculture statistics, British Columbia 1971 and 1981. British Columbia Ministry of Agriculture and Food, Victoria, B.C. 51 pp.

Mason, J.L. 1964. Yield and quality of apples grown under four nitrogen levels in uncultivated grass sod. Proc. Am. Soc. Hortic. Sci. 85:42-57.

Mason, J.L. 1969a. Effect of cultivation and nitrogen levels on storage quality, yield and color grade of Starking "Red Delicious" apple grown under grass sod. J. Am. Soc. Hortic. Sci. 94:78-80.

Mason, J.L. 1969b. Effect of cultivation and nitrogen on fruit quality, yield and color of McIntosh apples grown in irrigated grass sod cover crop. Can. J. Plant Sci. 49:149-154.

Mason, J.L.; Miltimore, J.E. 1959. Increase in yield and protein content of native bluebunch wheatgrass from nitrogen fertilization. Can. J. Plant Sci. 39:501-504.

Mason, J.L.; Miltimore, J.E. 1964. Effect of nitrogen content of beardless wheatgrass on yield response to nitrogen fertilization. J. Range Manage. 17:145-147.

Mason, J.L.; Miltimore, J.E. 1969. Yield increases from nitrogen on native range in southern British Columbia. J. Range Manage. 22:128-131.

Mason, J.L.; Miltimore, J.E. 1970. Yield increases from fertilizer on reed canarygrass and sedge meadows. Can. J. Plant Sci. 50:257-260.

Mason, J.L.; Miltimore, J.E. 1972. Ten years' yield response of beardless wheatgrass from a single nitrogen application. J. Range Manage. 25:269-272.

Maynard, D.G.; Bomke, A.A. 1980. The response of a grass - legume sward to poultry manure. Can. J. Soil Sci. 60:451-459.

McLean, A.; Nicholson, H.A.; van Ryswyk, A.L. 1963. Growth, productivity and chemical composition of a sub-alpine meadow in interior British Columbia. J. Range Manage. 16:235-240.

Miltimore, J.E.; Mason, J.L.; Rogers, C.B.W. 1962. Increase in seed production from nitrogen fertilization of native beardless wheatgrass. Can. J. Soil Sci. 42:359-364.

Molnar, J. 1961. The effect of varying levels of nitrogen fertilizers on the growth of peach trees and on the nitrogen, mineral and pigment content of the leaves. Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Neilsen, G.H.; Hogue, E.J. 1985. Effect of orchard soil management on the growth and leaf nutrient concentration of young dwarf "Red Delicious" apple trees. Can. J. Soil Sci. 65:309-315.

Neilsen, G.H.; Hoyt, P.B. 1982. Soil pH variation in British Columbia apple orchards. Can. J. Soil Sci. 62:695-698.

Neilsen, G.H.; Meheriuk, M.; Hogue, E.J. 1984. The effect of orchard floor management and nitrogen fertilization on nutrient uptake and fruit quality of "Golden Delicious" apple trees. HortScience 19:547-550.

Neilsen, G.H.; Stevenson, D.S. 1986. Effects of frequency of irrigation on nutrient uptake of apple trees. Can. J. Plant Sci. 66:177-180.

Nelson, C.H. 1963. Fertilizer recommendations for British Columbia. British Columbia soil workshop report of meeting no. 2. British Columbia Department of Agriculture, Kelowna, B.C., pp. 32-37.

Nyborg, M. 1961. The effect of fertilizers on emergence of cereal grains, flax and rape. Can. J. Soil Sci. 41:89-98.

Nyborg, M.; Hennig, A.M.F. 1969. Field experiments with different placements of fertilizers for barley, flax and rapeseed. Can. J. Soil Sci. 49:79-88.

Nyborg, M.; Hoyt, P.B. 1978. Effects of soil acidity and liming on mineralization of soil nitrogen. Can. J. Soil Sci. 58:331-338.

Phillips, D. 1976. Mineralization of nitrogen from deep pit poultry manure. Unpublished B.Sc.(Agric.) thesis, University of British Columbia, Vancouver, B.C.

Pringle, W.L.; van Ryswyk, A.L. 1965. Response of water sedge in the growth room to fertilizer and temperature treatments. Can. J. Plant Sci. 45:60-66.

Pringle, W.L.; van Ryswyk, A.L. 1967. Response of reed canarygrass on sedge - organic soil to fertilizer levels and temperature in the growth room. Can. J. Plant Sci. 47:305-310.

Pringle, W.L.; van Ryswyk, A.L. 1968. Carry-over effects of high fertilizer rates on native sedge bog vegetation in interior British Columbia. Can. J. Plant Sci. 48:49-55.

Rice, W.A. 1980. Seasonal patterns of nitrogen fixation and dry matter production by clovers in the Peace River region. Can. J. Plant Sci. 60:847-858.

Rice, W.A.; Penney, D.C.; Nyborg, M. 1977. Effects of soil acidity on rhizobia numbers, nodulation and nitrogen fixation by alfalfa and red clover. Can. J. Soil Sci. 57:197-203.

Ross, G.J.; Hoyt, P.B.; Neilsen, G.H. 1985. Soil chemical and mineralogical changes due to acidification in Okanagan apple orchards. Can J. Soil Sci. 65:347-355.

Schaefer, D.G. 1978. Climate. Page 5 in K.W.G. Valentine et al., eds. The soil landscapes of British Columbia. Resource Analysis Branch, British Columbia Ministry of Environment, Victoria, B.C. 197 pp.

Sparks, F.P. 1928. The nitrifying organisms isolated from British Columbia soils. Unpublished M.S. thesis, University of British Columbia, Vancouver, B.C.

Stevenson, F.J., ed. 1982. Nitrogen in agricultural soils. Agronomy No. 22. American Society of Agronomy, Madison, Wisc. 940 pp.

Valentine, K.W.G.; Sprout, P.N.; Baker, T.E.; Lavkulich, L.M. 1978. The soil landscapes of British Columbia. Resource Analysis Branch, British Columbia Ministry of Environment, Victoria, B.C. 197 pp.

van Adrichem, M.C.J.; Tingle, J.N. 1975. Effects of nitrogen and phosphorus on the yield and chemical composition of meadow foxtail. Can. J. Plant Sci. 55:949-954.

van Ryswyk, A.L. 1985. Tentative fertilizer recommendations for irrigated silage corn in B.C. southern interior. Contribution to the Enderby producers meeting. Mimeograph, Agriculture Canada Research Station, Kamloops, B.C. 11 pp.

van Ryswyk, A.L.; Hubbard, W.A.; Miltimore, J.E. 1973. Beef production potential and chemical composition of fertilized and unfertilized sedge hays grown on an organic soil of interior British Columbia. Can. J. Anim. Sci. 53:181-186.

van Ryswyk, A.L.; Pringle, W.L.; Neufeld, J.H. 1974. Response to reed canarygrass grown on ten British Columbia organic soils to N, P, K, and lime. Can. J. Soil Sci. 54:273-285.

Waldie, G.; Wright, S.B.M.; Cohen, R.D.H. 1983. The effects of advancing maturity on crude protein and digestibility of meadow foxtail (Alopecurus pratensis) and timothy (Phleum pratense). Can. J. Plant Sci. 63:1083-1085.

West, P.M. 1937. The influence of Wilder's bios on nodule bacteria and legumes. Unpublished M.S.A. thesis, University of British Columbia, Vancouver, B.C.

Wilcox, J.C. 1949. Some factors affecting apple yields in the Okanagan Valley. VI. Contents of N, P and K in the terminal shoots. Sci. Agric. 29:424-436.

Wilcox, J.C.; Hoy, B.; Palmer, R.C. 1947. Orchard fertilizer tests in the Okanagan Valley. Sci. Agric. 27:116-129.

Williams, R.J.; Broersma, K.; van Ryswyk, A.L. 1979. The effects of nitrogen fertilization on water use by crested wheatgrass. J. Range Manage. 32:98-100.