Soil and Plant Analysis for Agricultural and Environmental Research in Canada

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The Diamond Jubilee Symposium on the "Management of land and water resources for sustainable agriculture and environment", organized by the Indian Society of Soil Science, is of great interest to Canadian soil scientists. In 1988, Canada hosted the 7th North American Forest Soils conference in Vancouver, British Columbia. The theme was "Sustainable productivity of forest soils" (Gessel *et al.* 1990). In 1992 we organized the Environmental Soil Science conference in Edmonton, Alberta. In 1993 the International Workshop on Sustainable Land Management for the 21st Century was held in Lethbridge, Alberta. A Symposium on Sustainable Cropping was held during 1994 in Regina, Saskatchewan. We will be involved in the organization of the 1995 International Symposium on Soil and Plant Analysis: "Quality of soil and plant analysis in view of sustainable agriculture and the environment" to be held in Wageningen, the Netherlands.

The third International Symposium on Soil Testing and Plant Analysis was held in Olympia, Washington in August 1993. The plenary session on the status of soil and plant analysis in the world included the following papers: Byron Vaughan (USA), Victor Houba (the Netherlands), Ewald Schnug (Germany), Gyorgy Varallyay (Hungary), Lindsay Campbell (Australia), Marty Farina (South Africa), Bernardo Van Raij (Brazil), and Yash Kalra (Canada). My paper (Kalra 1993b) dealt with the status of soil and plant analysis in Canada.

The Results of a Survey

In 1991 at the International Symposium on "Soil Testing and Plant Analysis in the Global Community" held at Orlando, Florida, I presented a paper with Dr. J. Benton Jones, Jr. on the soil testing and plant analysis activities in the United States and Canada. We reported results of a survey conducted among the public and private soil and plant analysis laboratories (Jones & Kalra 1992). The survey forms were mailed to 450 laboratories in the USA and 201 in Canada. There were 114 replies from the USA and 83 from Canada. Some of the results of the Canadian laboratories are given in tables 1-3. It was found that many laboratories have fully integrated multi-disciplinary professional scientific staff including soil scientists, organic and inorganic chemists, and microbiologists.

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Table 1. *Type of laboratory ownership*

Classification	% of laboratories
Individually owned	20
University	11
Corporation	18
Province operated	51

Source : Jones, Jr. and Kalra (1992)

Table 2. *General laboratory description in terms of primary analytical service*

Laboratory description	% of laboratories
Primarily soil testing	12
Primarily plant analysis	0
Both soil testing and plant analysis	22
Wide range of analytical services including soil tests and plant analysis	66

Source : Jones & Kalra (1992)

Laboratories Where Soil and Plant Analysis Work is Done in Canada

1. Canadian Forest Service, Natural Resources Canada : The CFS laboratories are shown in figure 1.
2. Agriculture and Agri-food Canada : The major research centres are shown in figure 2.
3. Environment Canada : Laboratories at several locations, *e.g.*, Vancouver (British Columbia), Edmonton (Alberta), Burlington (Ontario), Ottawa (Ontario), and Dartmouth (Nova Scotia).
4. Universities : *e.g.*, University of British Columbia (Vancouver), University of Alberta (Edmonton), University of Calgary (Calgary), University of Saskatchewan (Saskatoon), University of Manitoba (Winnipeg), University of Guelph (Guelph), and McGill University (Montreal).
5. Provincial Research Councils : *e.g.*, Alberta Research Council (Edmonton) and Saskatchwan Research Council (Saskatoon).
6. Private laboratories, *e.g.*, Agat, Chemex, Chemical and Geological, Enviro-Test and Norwest.

Some statistics for Canada include : population (1993) 28.8 million, total area 997.0 million ha, land area 921.5 million ha, forest land 416.2 million ha, national parks 21.7 million ha and provincial parks 22.9 million ha.

Some of the Research on Soil and Plant Analysis Conducted at the Northern Forestry Centre

The results of the evaluation of extractants for the determination of available Mn in forest nursery soils were presented at the 12th International Congress of Soil Science held in New Delhi (Kalra & Edwards 1982). Several extractants were evaluated (Maynard *et al.* 1987) for the determination of sulphur in organic horizons

Fig.1. Analytical laboratories, Canadian Forest Service

Fig. 2. Major research centres, Agriculture and Agri-food Canada (1994)

of forest soils by ion chromatography (IC) and inductively coupled plasma-atomic emission spectrometry (ICP-AES). A microwave digestion procedure was developed for multi-element determinations in tree foliage by ICP-AES. The results are given in table 4 (Kalra *et al.* 1989).

Table 3. *Type of laboratory equipment, and analytical instruments*

Item	% of laboratories
Power driven soil crusher	48
Udy mill	10
Wiley mill	55
Time controlled strirrer	30
Time controlled shaker	82
Power driven dispenser	37
Top loading balance	88
Analytical balance	93
Muffle furnace	85
Microwave digestion apparatus	28
pH meter	94
Conductivity meter	87
Specific ion meter	62
Spectrophotometer	78
Atomic absorption spectrometer	85
ICP plasma spectrometer	59
DC plasma spectrometer	7
Auto analyzer	70
Flow injection analyzer	20
Sulphur analyzer	21
Macro-Kjedhal apparatus	27
Micro-Kjeldahl apparatus	32
Automated Kjeldahl apparatus	29
Block digestor	80
HACH Kjeldahl apparatus	8
Dumas N analyzer	7
Ion analyzer	32

Source : Jones, Jr. & Kalra (1992)

A number of studies were carried out on the determination of cation exchange capacity (CEC). Automated (Auto-Analyzer and Kjeldhal analyzer) and manual (Kjeldahl) methods were evaluated for NH_4-N analysis in the determination of CEC of soils (Kalra & Maynard 1986). The results are presented in table 5. A mechanical vacuum extractor (MVE) was evaluated for the determination of CEC and extractable cations in calcareous soils. The results were presented at the 14th International Congress of Soil Science held in Kyoto, Japan (Kalra & Maynard 1990). We have conducted several experiments on the comparison of extractants for the determination of CEC and extractable cations by MVE. Some of the results obtained in a recent study (Kalra & Maynard 1994) are given in table 6. Information on the soils used presented in table 7.

Table 4. *Results (mg kg^{-1}) obtained by microwave digestion method compared with National Institute of Standards and Technology (NIST) values for citrus leaves and pine needles*

Element	NIST citrus leaves (SRM 1572)		NIST pine needles (SRM 1575)	
	Microwave results (n = 49)	NIST values	Microwave results (n = 42)	NIST values
Ca	31 300 ± 300 (3.3)[a]	31 500 ± 1 000	4 160 ± 271 (6.5)	4 100 ± 200
Mg	5 530 ± 150 (2.7)	5 800 ± 300	1 120 ± 47 (4.2)	1 200 ± 100
K	18 100 ± 660 (3.6)	18 200 ± 600	3 640 ± 93 (2.6)	3 700 ± 200
Na	154 ± 19 (12.3)	160 ± 20	16 ± 12 (75)	26 ± 9
Mn	20.7 ± 1.3 (6.3)	23 ± 2	667 ± 28 (4.2)	675 ± 15
P	1 340 ± 44 (3.3)	1 300 ± 200	1 190 ± 54 (4.5)	1 200 ± 200
S	3 880 ± 106 (2.7)	4 070 ± 90	1 130 ± 39 (3.4)	1 180 ± 13
Fe	75 ± 13 (17.3)	90 ± 10	140 ± 16 (11.4)	200 ± 10
Al	76 ± 15 (19.7)	92 ± 15	401 ± 30 (7.5)	545 ± 30

[a] Coefficient of variation (%).
Source : Kalra et al. (1989)

Table 5. *Cation exchange capacity [(cmol (p^+) kg^{-1}] by different methods of determining NH_4–N in Canada Soil Survey Committee (CSSC) samples*

Method	CSSC 9 (Csa horizon)			CSSC 13 (Typic Fibrisol Sphagnum bog "Of" horizon)		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
Kjeldahl	14.3	0.67	4.7	123.0	3.33	2.7
Auto analyzer	14.1	0.97	6.9	123.2	7.72	6.3
Kjeltec	14.2	0.48	3.3	124.1	4.85	3.9

Source : Kalra & Maynard (1986)

Table 6. *Cation exchange capacity by different extracting solutions (mean ± standard deviation), cmol (p^+) kg^{-1}, n = 4*

Sample	Extractant						
	1.0*M* NH_4OAc pH 8.2	1.0 *M* NH_4OAc pH 7.0	1.0 *M* NH_4Cl pH 8.4	1.0 *M* NH_4Cl unbuffered	i) 1.0 *M* $BaCl_2$ pH 8.2 ii) 0.5 *M* $MgCl_2$	i) 0.1 *M* $BaCl_2$ unbuffered[b] ii) 0.5 *M* $MgCl_2$	i) 0.4 *M* NaOAc/0.1 *M* NaCl/EtOH ii) 0.5 *M* Mg $(NO_3)_2$
ECSS[c]4	3.71c ±0.07	3.69c ±0.05	3.84c ±0.05	3.64c ±0.16	5.88b ±0.51	10.61a ±1.80	4.03c ±0.02
ECSS 7	32.18c ±0.46	32.33c ±0.33	31.06c ±0.18	28.67d ±3.03	43.95b ±0.68	49.51a ±1.35	28.43d ±0.91
ECSS 8	21.19c ±0.62	21.23c ±0.42	21.28c ±0.38	20.36d ±0.37	28.44a ±0.61	27.17b ±0.32	18.91c ±0.20

Source : Kalra & Maynard (1994)

Means for each sample followed by the same letter (s) do not differ significantly ($p \leq 0.05$).

[a]pH = 5.0.

bpH = 5.5

[c]ECSS = Expert Committee on Soil Survey.

Table 7. *Soils used for the determination of cation exchange capacity by different extracting solutions*

Sample	Soil horizon	Great group	pH ($CaCl_2$)	$CaCO_3$ equivalence (%)
ECSS 4	Ck	Grey Brown Luvisol	8.0	23.0
ECSS 7	Ah	Black	7.2	0.0
ECSS 8	Bnt	Solonetz	7.4	0.0

source : Karla & Maynard (1994)

Details of some other work done at the Northern Forestry Centre have been published from line to line. (Ali & Kalra 1974; Ali *et al.* 1988; Edwards & Kalra 1986; Edwards *et al.* 1978; Edwards *et al.* 1981; Feng 1992; Feng *et al.* 1989; Hogan & Maynard 1984; Kalra 1977; Kalra 1993a; Kalra 1994; Kalra & Ali 1970; Kalra *et al.* 1990; Kalra & Radford 1975; Maynard 1990; Maynard & Addison 1985; Maynard & Kalra 1993; Maynard *et al.* 1993; Maynard *et al.* 1994; Sidhu & Feng 1993; Singh & Kalra 1975).

Some of the Research on Soil and Plant Analysis Carried out at Other Establishments in Canada

Although a discussion of the work done at other establishments in Canada is outside the scope of this paper, still some of the references are given below:

i) *Plant analysis* : Tel (1989a, 1989b), Tel *et al.* 1992, Webber (1972, 1974).

ii) *Soil chemical analysis* : Abboud (1992), Acton *et al.* (1963) Bailey (1966) Bates (1990); Bates and Richards (1993); Beaton *et al.* (1968); Callin (1994); Carson *et al.* (1972); Chakrabarti *et al.* (1994); Clark (1965); Dabeka and Ihnat (1994); Dormaar and

Webster (1963); Fan and MacKenzie (1993); Gupta (1979, 1993); Gupta and Stewart (1978); Hendershot and Doquette (1986); Hodgins and Karamanos (1992); Hoyt and Nybord (1972); Janzen and Chang (1988); Karamanos *et al.* (1992); Khan and Webster (1968); Kowalenko (1985); Kratochvil (1992); Lowe and Delong (1963); MacLean *et al.* (1964); Mahendrappa and Kingston (1991); Malhi *et al.* (1989); Neilsen *et al.* (1989); Pawluk (1967); Qian *et al.* (1992); Rennie (1966); Richards and Bates (1988); Robertson (1962); Saggar *et al.* (1981); Sheldrick (1986); Simard and Deshenes (1992); Singh and Brydon (1969); Skinner and Halstead (1958); Skinner *et al.* (1959); Soon (1992); Spinks and Barber (1947); Stewart and Tiessen (1987); Subramanian and Iyengar (1994); Tel and Covert (1992); Tiessen *et al.* (1981); Tran and Giroux (1985); Turner (1960); Turner and Skinner (1960); Van Lierop (1989); Van Lierop and Gough (1989); Walker and Bentlry (1961); Wang *et al.* (1987).

iii) *Soil physical analysis* : Cairns and van Schaik (1968); Culley and McGovern (1990); McBride and Bober (1989); Reynolds and Elrick (1991); Reynolds *et al.* (1983); Toogood and Peters (1953); Topp *et al.* (1984); Warkentin and Bozozuk (1961).

iv) *Soil biological analysis* : Campbell *et al.* (1988); Cerrato *et al.* (1991); Germida (1985); Juma *et al.* (1984); Kimpinski and Welch (1971); Olsen *et al.* (1983); Rennie (1981); Voroney and Paul (1984).

v) *Soil biochemical analysis* : Anderson *et al.* (1974); Chae and Lowe (1981); Dormaar (1970); Fox (1985); Mathur and Levesque (1988); McGill *et al.* (1975); Naidia and Huang (1992); Parent *et al.* (1980, 1982); Roberts *et al.* (1989); Schnitzer and Schuppli (1989); Schoenau and Bettany (1987); Szmigielska *et al.* (1994); Zoltai (1978).

vi) *Soil mineralogical analysis* : Bui and Mermut (1989); Kodama *et al.* (1977); Ross *et al.* (1989).

vii) *Analysis of frozen soils* : Kay *et al.* (1985); Konard (1987); Williams and Smith (1989).

Analytical Techniques

The Kjeldahl method is considered to be the oldest of all analytical procedures used in Canada and many other countries around the world (Morries 1983). It was introduced by John G.C.T. Kjeldhal at a meeting of the Danish Chemical Society on March 7, 1883, and published later that same year in Zeitschrifte fur Analytische Chemie (Kjeldahl 1883). Although, the basic principle of the test procedure has remained much the same since 1883, the distillation and determination of NH_4-N have significantly improved. Many Canadian laboratories now use Kjeltec Auto 1030 Analyzer. Atomic absorption spectrophotometry, continuous flow analysis, ion chromatography, inductively coupled plasma-atomic emission spectroscopy and other techniques used in Canada are given in the manuals by Carter (1993) and Kalra and Maynard (1991).

Following extractants have been used for determining available K (Table 8)

Table 8. *Canadian soil test extraction methods for available potassium*

Province	Extractant	Soil/extractant ratio	Shaking time (min)	Analytical instrument
Newfoundland	CH_3COONH_4	1:10v/v	15	Atomic absorption
Prince Edward Island	Mehlich III	1:10 w/v	5	ICP-AES
Nova Scotia	Double acid	1;10 v/v	5	ICP-AES
New Brunswick	Mehlich I	1;10 v/v	30	Atomic absorption
Quebec	CH_3COONH_4	1:10 v/v or	5	Flame emission
Ontario	Mehlich III	w/v	15	Flame emission
Manitoba	CH_3COONH_4	1:10 v/v	30	Flame emission
Saskatchewan	CH_3COONH_4	1:10 w/v	30	Flame emission
Alberta	$NaHCO_3$	1:20 v/v	5	Flame emission
British Columbia	CH_3COONH_4	1:5 v/v	5	ICP-AES
	$CH_3COOH+NH_4$	1:10 v/v		

Source: Bates and Richards (1993)

Methods Manuals

McKeague's manual (1978) has been used for many years as a reference manual for soil analysis in Canada. Now this has been extensively revised and published as a special publication of the Canadian Society of Soil Science (Carter 1993). A number of forestry research centres, including all the laboratories of the Canadian Forest Service use Kalra and Maynard's methods manual (1991) for forest soil and plant analysis. This publication is also available in French (Kalra & Maynard 1992). Some of the other manuals available are those of Kalra (1971), Kowalenko (1993), Laverty and Bollo-Kamara (1988). Lavkulich (1981), Neufeld (1980) and Sheldrick (1984).

Quality Assurance of Analytical Data

Quality assurance principles are followed to ensure reliability of analytical results. They consist of quality control and quality assessment procedures. A quality control checklist used at the Environment Canada laboratories is given below:

Quality control at an Environment Canada Laboratory (N. Gurprasad, personal communication)

Quality Control Checklist

Method development
- Method performance determination
  - Instrument linear range
  - Bias (spikes, reference material)
  - Blanks
  - Precision (replicates)
  - Detection limit

Approved written method

Capability demonstration

Analysis plan approved

Legal samples

- Photographs
- Chain of custody

Sample integrity maintenance

Record keeping (immediate, clear, concise and complete)

- Procedures used
- Observations
- Results
- Traceability

Calibration

- Curve study
- Stability check

Instrument maintenance (service, checks, documentation)

Clean-up column calibration

Method performance monitoring

- Quality Control (QC) Samples
  - Method blanks
  - Duplicates
  - Spikes
  - Reference material

Report review by Quality Assurance/Quality Control (QA/QC) officer and senior chemist

Filing

Check Sample Programmes

To ensure that a laboratory produces credible analytical results, it is important to participate in collaborative studies utilizing check samples as a method implementing a quality control procedure. The Northern Forestry Centre has participated and/or is participating in the following national and international soil and plant analysis interlaboratory round robins:

1. Acid Rain Direct/Delayed Response Project (DDPR), Environmental Protection Agency, Las Vegas, Nevada, USA (Bartz *et al.* 1987).
2. Alberta Institute of Pedology (AIP), Edmonton, Alberta, Canada (Heaney *et al.* 1988)
3. Canadian Soil Survey Committee (CSSC), Ottawa, Ontario, Canada (McKeague *et al.* 1978)
4. Energy Resources Conservation Board (ERCB), Calgary, Alberta, Canada (M. Korchinski, personal communication).
5. Expert Committee on Soil Survey (ECSS), Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada (Sheldrick & Wang 1987).
6. International Soil Exchange (ISE), Wageningen Agricultural University, Wageningen, the Netherlands (Houba *et al.* 1993).

7. International Union of Forestry Research Organizations (IUFRO), the Netherlands (de Wit 1973; Kalra & Edwards 1974; Van Goor 1978; van Goor *et al.* 1971).
8. LABEX Program, International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands (Pleijsier 1985).
9. Long Range Transport of Air Pollutants (LRTAP), Canadian Forest Service, Sault Ste. Marie, Ontario, Canada (Kalra *et al.* 1994).
10. Western Enviro-Agricultural Laboratory Association (WEALA), Edmonton, Alberta, Canada (Kalra & Maynard 1987; Kalra & Peters 1981).

An Example of a Check Sample Programme

In the interlaboratory study of the Canadian Forest Service, plant materials were sent to several laboratories (which included federal government, provincial government, university, as well as some private laboratories) analyzing plant tissue samples for any of the federal and/or provincial air pollution and/or acidic precipitation research and/or monitoring programmes. The laboratories were asked to analyze any or all of the following elements: C, N, P, K, Ca, Mg, S, Fe, Mn, B, Zn, Cu, Mo, Cl, Na, Al, Ni, Pb, Cd, Hg, Co, and As. The results of a recent study were presented at the International Symposium on Soil Testing and Plant Analysis, Olympia, Washington, USA (Kalra *et al.* 1994). The results obtained by 17 laboratories for P are given in table 9.

Table 9. *Results of the interlaboratory study: Concentrations of P (mg g^{-1}) in plant materials*

Audit sample	Mean	Median	SD	SE mean
8604 RPS (Red Pine Stem)	0.1162	0.0900	0.0774	0.0188
8608 RPN (Red Pine Needles)	0.4447	0.4500	0.0710	0.0172
8609 ROL (Red Oak Leaves)	0.3951	0.4010	0.1099	0.0266
8616 TAS (Trembling Aspen Stem)	0.3930	0.4000	0.1498	0.0363
8720 EHN (Eastern Hemlock Needles)	1.5236	1.5220	0.2618	0.0635
8724 BSN (Black Spruce Needles)	1.2700	1.2700	0.1154	0.0280
8827 EBL (White Birch Leaves)	2.2882	2.2400	0.1924	0.0467
9129 HHL (Hop-Hornbeam Leaves)	1.4984	1.4860	0.1332	0.0323
9130 HHS (Hop-Hornbeam Stem)	0.4580	0.0800	1.3420	0.3250
9132 ELN (Eastern Larch Needles)	1.9094	1.8540	0.2117	0.0514

Source: Kalra *et al.* (1994)

Proficiency Testing Programmes for Soil Testing Laboratories

At present, several Canadian laboratories are participating in the following two programmes designed to evaluating performance:

1. Proficiency Testing Programme of the Soil and Plant Analysis Council

This programme is coordinated by Dr. J. Benton Jones, Jr., Soil and Plant Analysis Council, Georgia University Station, Athens, Georgia, USA. The Board of Directors of the Council approved the Proficiency Testing at its March 1994 meeting in Atlanta, Georgia, USA.

2. Western States Agricultural Laboratory Exchange Programme

A soil and plant sample exchange programme has been initiated for agricultural laboratories. The program is jointly sponsored by the University of California, Davis and Utah State University. The Western States Programme is an expansion of the current Utah State Soil and Plant Exchange Programme. It is coordinated by Janice Kotuby-Amacher, Utah State University, Logan, Utah, USA, and Robert O. Miller, University of California, Davis, California, USA.

Schedule of Fees

How much does it cost to get samples analyzed at a Canadian soil testing laboratory? Approximate price/sample is given in table 10.

Table 10. *Cost of soil and plant analysis*

Analysis	Approximate cost per sample ($ Can)
Soil analysis	
a) Chemical analysis of soils	
pH and EC	6-10
Detailed salinity	35
B	6-20
Cl	8
CEC	25
Exchangeable Ca,Mg,K,and Na	25
Organic C	7-25
Inorganic C	20
Total C	20
b) Physical analysis of soils	
Texture,qualitative	4
Particle-size analysis (Bouyoucos method)	25
Particle-size analysis (Pipette method)	30-50
Sand fractionation	20[b]
Atterberg limits	50
Available moisture (1/3 and 1/5 bar limits)	25
Water percolation and saturated hydraulic conductivity	50
c) Farm soil testing packages	20-25
d) Soil survey package	150
e) Lawn and garden package, greenhouse medium	30
Plant analysis	
Total N	20-25
Other elements: Digestion	25
Determination	3 (per element)
Cl	12
Environmental analysis	
Saltwater spill analysis	60
Oil spill analysis	80
Oil content	35

[a]Cost depends on method of analysis and number of samples.
[b]In addition to particle size analysis by the pipette method.

Journals

1. Canadian Journal of Soil Science

It is the official journal of the Canadian Society of Soil Science. This journal, published by the Agricultural Institute of Canada in cooperation with the Canadian Society of Soil Science, is devoted to original research and invited reviews reported in English or French in the various fields of soil science including agriculture, ecology, engineering, environment, forestry, geology and geography. Further information is available from the Editor: Dr. S.C. Sheppard, AECL Research, Whiteshell Laboratories, Pinawa, Manitoba, Canada ROE 1L0.

2. Canadian Journal of Plant Science

It is the official journal of the Canadian Society of Agronomy, the Canadian Society of Horticultural Science and the Canadian Pest Management Society. This journal, published by the Agricultural Institute of Canada, is devoted to original research results reported in English and French. Manuscripts concerned with any aspects of plant science are considered. Further information is available from the Editor: Dr. C. Chong, Horticultural Research Institute of Ontario, Vineland Station, Ontario, Canada LOR 2E0.

3. Canadian Journal of Forest Research

It is published by the National Research Council of Canada. Further information is available from the Editor: Dr. William M. Cheliak, Canadian Journal of Forest Research, Natural Resources Canada, Canadian Forest Service, Forest Pest Management Institute, P.O. Box 490, 1219 Queen Street East, Sault Ste. Marie, Ontario, Canada, P6A 5M7.

Societies

1. Canadian Society of Soil Science

The Canadian Society of Soil Science (CSSS) is a non-governmental, non-profit organization for scientists, engineers, technologists, administrators and students involved in professional soil science. Its objectives are: (1) to promote the wise use of soil for the benefit of all society; (2) to promote research and practical application of findings in soil science and (3) to promote information and technology exchange among people involved in professional soil science. The 1994-95 executive consists of:

President	A.Fedkenheuer, Calgary, Alberta
President-Elect	U.C. Gupta, Charlottetown, Prince Edward Island
Past President	K.B. MacDonald, Guelph, Ontario
Secretary	Y.P. Kalra, Edmonton, Alberta
Treasurer	A.V. Rodd, Nappan, Nova Scotia
Eastern Councillor	R.R. Simard, Sainter-Foy, Quebec
Western Councillor	G.H. Neilsen, Summerland, British Columbia
AIC Representative	W.W. Pettapiece, Edmonton, Alberta

Membership application forms and further information are available from : Canadian Society of Soil Science, P.O. Box 21018, Westend Postal Outlet, Brandon, Manitoba, Canada R7B 3W8.

2. Group of Analytical Laboratories

The Group of Analytical Laboratories (GOAL) is a working group of the analytical services laboratories of the Canadian Forest Service, Natural Resources Canada. The common objective of the group is to provide cost-effective, accurate, timely analyses on soil and plant samples to scientific teams and their clients. It provides a forum for exchange of information on topics of mutual interest among analysts to improve laboratory operations. The working group consists of seven members, the supervisors of analytical laboratories of each of the six forestry centres and one institute. The fourth annual meeting was held at Sault Ste. Marie, Ontario, October 7-9, 1993.

3. International Soil and Plant Analysis Council, Inc.

The Council was established in 1969 to promote soil testing and plant analysis. Its goals include fostering the efficient use of nutrient resources, maximizing profits, and encouraging the proper management of soils. Reflecting current trends, a more recent objective is environmental protection. In response to the growing need to identify and locate soil testing and plant analysis laboratories, the Council has established the Soil and Plant Analysis Laboratory Registry. The Registry lists, by geographical area, the name, location, telephone number, and services provided of each participating laboratory in the USA and Canada (Council on Soil Testing and Plant Analysis 1992). The main thrust of the council has been the organization of the following Symposia on Soil Testing and Plant Analysis: I.Fresno, California, USA: August 14-19, 1989; II. Orlando, Florida, USA, August 22-27 1991; III. Olympia, Washington, USA, August 14-19, 1993, and IV. Wageningen, the Netherlands, August 5-10, 1995

4. AOAC International (formerly AOAC, Association of Official Analytical Chemists)

To date, none of the methods for soil analysis have been validated by the AOAC International. In 1990, the Soil Science Society of America (SSSA) and AOAC INTERNATIONAL decided to conduct collaborative studies for this purpose. pH was chosen as the first study to be carried out because it is one of the most important properties. A total of 53 laboratories are participating in the pH study (Canada 26, India 2, Israel 1, USA 24). Many AOAC validated procedures eventually are chosen as official methods in various organizations. This method is being validated under the direction of the AOAC General Committee on Feeds, Fertilizers, and related Topics: antibiotics in feeds, drugs in feeds, feeds, fertilizers and agricultural liming material, nutrients in soils, tobacco, and veterinary analytical toxicology.

Dr. Charles Focht, Lincoln, Nebraska, USA is the General Referee for the study "Nutrients in soil". The names of the Associate Referees are as folows: M Amir Ali, Saudi Arabia (soil quality), Bryan Hopkins, Manhattan, Kasnas (available phosphorus in soil), Yash P. Kalra, Edmonton, Alberta, Canada (pH measurements in soil), and Maurice E. Watson, Wooster, Ohio (available potassium in soil). The details on the pH study were presented at the Soil and Environmental Chemistry workshops in Olympia, Washington, USA (Kalra 1993a, 1994). The Soil and Environmental Chemistry workshops of the AOAC International Pacific Northwest

Regional Section are co-chaired by Willian J. Walker from the USA and Yash P. Kalra from Canada.

5. International Society of Soil Science (ISSS)

   Several Canadian soil scientists participate in the activities of the International Society of Soil Science

6. British Columbia Soil and Tissue Testing Council, Kelowna, British Columbia
7. I'Association Quebecoise des specialistes en sol, Quebec
8. Pacific Regional Society of Soil Science (PRSSS), Vancouver, British Columbia
9. Western Enviro-Agricultural Laboratory Association (WEALA). Edmonton, Alberta

Laboratory Safety

Three federal legislations have been enacted that are integral to the betterment of the quality of life of all Canadians (Figure 3). In Canada, all laboratory personnel

Fig. 3. Transportation of dangerous goods act relationship to other legislation.

are required to undergo Workplace Hazardous Materials Information System (WHMIS) training.

Mobile Laboratory Services for On-site Analysis

Some Canadian laboratories provide fully equipped mobile units for analysis in the field. For example, one environmental laboratory in Alberta provides the following analyses.

Target polynuclear aromatic hydrocarbon (PAH) compounds

Creosote components

Benzene, toluene, ethyl benzene, and xylene (BTEX), total petroleum hydro carbon (TPH), and phenols

Polychlorinated biphenyls (PCBs)

Mercury analysis

Flash points

pH and electrical conductivity (EC)

Metals analysis

Pesticide and herbicide analysis

Industrial hygiene - organics and inorganics

Asbestos and fibre counts

The Acid Rain National Early Warning System (ARNEWS): Canada's national forest health monitoring network

Air pollution can affect forests in several ways. It can directly damage plant tissues. It can alter forest soils, thus changing the availability of nutrients to plants. Ten years ago, Canadian Forest Service established the Acid Rain National Early Warning System (RNEWS) to detect early signs of air pollution and climate change damage to Canada's forests (Fig. 4).

Recent Developments

1. Several Canadian laboratories have been privatized, *e.g.*, British Columbia Soil Testing Laboratory and Saskatchewan Soil Testing Laboratory. The focus of Alberta Soil Testing Laboratory has shifted from analyzing samples for farmers to performing diagnostic work.

2. Private laboratories report that in the past, about 60% of the work was related to agricultural soils while presently 70% of the work deals with environmental analysis (Callin 1994).

3. The biggest change has been in the QA/QC programme to meet the data quality objectives (DQOS) of a specific project.

4. Now there is a greater emphasis on laboratory accreditation, *e.g.*, Standards Council of Canada, Canadian Association for Environmental Analytical Laboratories (CAEAL).

5. An increased demand for chemical analysis has largely resulted from tighter regulations.

6. While the laboratories generally analyzed samples for fertility and pedological studies, now there is a greater need for the determination of PCB, pesticides, and herbicides.

7. At some universities, soil science and environmental science departments are being amalgamated. For example, this year at the University of Alberta, the Renewable Resources department has been formed by the amalgamation of soil science and forest science.

Fig. 4. Location of the Acid Rain National Early Warning System plots

Challenges and Opportunities in the Year 2000 and Beyond

The 21st century is just around the corner. Will there be a difference? The only certainty is the uncertainty. Are we ready for the changes?

1. Population explosion: world population: 5.6 billion (1993); projections: 10-14 billion in 2050 (population increasing by about 94 million people every year).
2. Pollution
3. Global warming: Greenhouse effect (caused mainly by vehicle exhaust gases)
4. Depletion of the ozone layer
5. Biodiversity
6. Information overload: trying to keep up-to-date
7. Downsizing: jobs in peril, workforce adjustment
8. Budget cuts
9. Technology revolution
10. Automation
11. Computers: cheap, fast computer power
12. For the laboratory:
    a. Accreditation
    b. Certification: meeting new regulatory standards
    c. Generating defensible data
    d. QA/QC
    e. Waste reduction
    f. Minimizing the generation of hazardous waste
    g. Recycling: disposal of reagents and instruments
    h. Instrumental hybridization, e.g., GC-MS, ICP-MS
    i. Laboratory safety
    j. Data handling
    k. Compact and low-cost laboratory instrumentation

The future looks challenging; the opportunities are endless.

References

Abboud, S.A. (1992) Total heavy metal analysis methods: Comparison of various digestion techniques. Pages 2-1 to 2.32 *in* S.A. Abboud, editior, Proceedings of the 4th Annual WEALA Workshop on Heavy Metals in the Environment; April 28, 1992. Western Enviro-Agricultural Laboratory Association, Edmonton, Alberta, Canada

Acton, C.J., Paul, E.A. & Rennie, D.A. (1963) Measurement of the polysaccharide content of soils. *Can. J. Soil Sci.* **43**, 141-150.

Agriculture and Agri-food Canada (1994) Directory of Research, Agriculture and Agri-food Canada, Research Branch. Ottawa, Ontario, Canada. Publication 5252.

Ali, M.W.& Kalra, Y.P. (1974). Sodium contamination by filter paper. *J. Assoc. Off. Anal. Chem.* **57**, 762.

Ali, M.W., Zoltai, S.C. & Radford, F.G. (1988) A comparison of dry and wet ashing methods for the elemental analysis of peat. *Can. J. Soil Sci.* **68**, 443-447.

Anderson, D.W., Paul, E.A. & St. Arnaud, R.J. (1974) Extraction and characterization of humus with reference to clay-associated humus. *Can. J. Soil Sci.* **54**, 317-323.

Bailey, L.F. (1966) The availability of potassium to plants from several calcareous and non-calcareous Manitoba soils. M.Sc. Thesis, University of Manotoba, Winnipeg, Manitoba, Canada.

Bartz, J.K., Drouse, S.K., Cappo, K.A. Papp, M.L., Raab, G.A., Blume, L.J., Stapanian, M.A., Garner, F.C. & Coffey, D.S. (1987) Direct/delayed response project: quality assurance plan for soil sampling, preparation and analysis. U.S.Environmental Protection Agency, Washington, DC, USA.

Bates, T.E. (1990) Prediction of phosphours availability from 88 Ontario soils using five phosphorus soil tests. Commun. Soil. Sci. Plant Anal. 21, 1009-1023.

Bates, T.E. and Richards, J.E. (1993). Available potassium. pages 59-64 *in* M.R. Carter, editor. Soil Sampling and Methods of Analysis. Boca Raton, Florida, USA.

Beaton, J.D.,Burns, G.R & Platou, J. (1968) Determination of sulphur in soils and plant material. Technical *Bulletin* No. **14**. The Sulphur Institute, Washington, DC, USA.

Bui, E.N. & Mermut, A.R. (1989) Quantification of soil calcium carbonates by staining and image analysis *Can. J. Soil Sci.* **69**, 677-682.

Cairns, R.R. & van Schaik, J.C. (1968). Solonetzic soils and their physical properties as influenced by different cations Can J. Soil Sci. **48**, 165-172.

Callin, E. (1994) Soil analysis in Aberta: Present and future direction. Paper presented at the Western Enviro-Agricultural Labpratory Association and Alberta Water Analytical Chemists 7th Annual Technical Workshop on Environmental Sampling Analysis and Interpretation; April 12, 1994. Edmonton, Alberta, Canada.

Campbell, C.A., Jame, Y.W. & Dejong, R. (1988) Predicting net nitrogen mineralization over a growing season: model verification. *Can. J. Soil Sci.* **68**, 537-552

Carson, J.A., Crepin, J.M. & Nemunis-Siugzdinis, P. (1972) A sulfate-sulfur method used to delineate the sulfur status of soils. *Can. J. Soil Sci.* **52**, 278-281.

Carter, M.R., (editor) (1993) Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida, USA

Cerrato, M.E., Goh, T.B. & Racz, G.J. (1991) Comparison of biological and chemical methods for estimating nitrogen availability in a sewage sludge amended soil. Paper presented at the 37th Annual Meeting of the Canadian Society of Soil Science; July 29-31 1991. Fredericton, New Brunswick, Canada

Chae, Y.M. & Lowe, L.E (1981) Fractionation by column chromatography of lipids and lipid sulfur extracted from soils. *Soil. Biol. Biochem.* **13**, 257-260.

Chakrabarti, C.L., Cheng, J., Back, M.H. & Schroeder, W.H. (1994). Trace metal speciation in environmental samples by rotating disc electrode voltammetry. Paper presented at the 24th International Symposium on Environmental Analytical Chemistry; May 16-19, 1994. Organized by the International Association of Environmental Analytical Chemistry and the Centre for Analytical and Environmental Chemistry, Carleton University, Ottawa, Ontario, Canada.

Clark, J.S. (1965) The extraction of exchangeable cations from soils. *Can. J. Soil Sci.* **45**, 311-322.

Council on Soil Testing and Plant Analysis (1992) Soil and plant analysis laboratory registry for the United States and Canada. Athens, Georgia, USA.

Culley, J.L.B. & McGovern, M.A. (1990) Single and dual probe nuclear instruments for determining water contents and bulk densities of a clay loam soil. *Soil Tillage Res.* **16**, 245- 256.

Dabeka, R.W. & Ihnat, M. (1994) The quest for quality in environmental analytical data. Paper presented at the 24th International Symposium on Environmental Analytical Chemistry, May 16-19, 1994.

Organized by the International Association of Environmental Analytical Chemistry and the Centre for Analytical and Environmental Chemistry, Carleton University. Ottawa, Ontario, Canada.

de Wit, M (1973) International methods for chemical analysis (report on activities, 1971-73) IUFRO Subject Group S1.02, Working Party 3, For Res. Stn. De Dorschkamp, Wageningen, the Netherlands.

Dormaar, J.F. (1970) Phospholipids in chernozemic soils of southern Alberta. *Soil Sci.* **110**, 136-139.

Dormaar, J.F. & Webster, G.R. (1963) Determination of total organic phosphorus in soil by extraction methods. *Can. J. Soil Sci.* **43**, 35-43.

Edwards, I.K. & Kalra, Y.P. (1986) Soil Analysis: Impact on forestry. Paper presented at the 2nd Annual Western Enviro- Agricultural Laboratory Association Workshop on Soil Analysis: Imapcts on Agricultural and Resource Industries; February 26-27, 1986. Calgary, Alberta, Canada.

Edwards, I.K., Kalra, Y.P. & Radford, F.G. (1978) Chloride determination and levels in the soil plant environment. pp. 259- 260 In Abstracts for commission papers. *11th Int. Cong. Soil Sci; June* 19-27, 1978. University of Alberta, Edmonton Alberta, Canada.

Edwards, I.K., Kalra, Y.P & Radford, F.G (1981) Chloride determination and levels in the soil-plant environment. *Environ. Poll.* (Series B), **2**, 109-117.

Fan, M.X. & MacKenzie, A.F. (1993) A rapid method for measuring dynamic changes in pH of fertilizer microsites. *Can. J. Soil Sci.* **73**, 129-132.

Feng, J.C. (1992) A microcolumn method for hexazinone and metabolite residues in soil and vegetation *Can. J. Chem.* **70**, 1087-1092.

Feng, J.C., Feng, C.C. & Sidhu, S.S. (1989) Determination of hexazinone residue and its release from a granular formulation under forest conditions. *Can. J. For. Res.* **19**, 378-381.

Fox, C.A. (1985) Micromorphological characterization of Histosols. pp. 85-104 *In* L.A. Douglas and M.L. Thompson, editors. Soil Micro-morphology and Soil Classification. Special No. 15 *Soil Sci. Soc Am.* Madison, Wisconsin, USA.

Germida, J.J. (1985) Modified sulfur containing media for studying sulfur oxidizing microorganisms. pp. 333-344. *In* D.E. Caldwell, J.A. Brierley, and C.L. Brierley, editors. Planetary ecology. Van Nostrand Reinhold, New York, USA.

Gessel, S.P., Lacate, D.S., Weetman, G.F. & Powers, R.F. (1990) Sustained productivity of forest soils. Proceedings of the 7th North American Forest Soils Conference; July 24-28, 1988. University of British Columbia, Vancouver, British Columbia, Canada.

Gupta, S.K. & Stewart, J.W.B. (1978) An automated procedure for determination of boron in soils, plants and irrigation waters. *Schweiz. Landwirtscha. Forsch.* **17**, 51-55.

Gupta, U.C. (1979) Some factors affecting the determination of hot-water soluble boron from podzol soil using azomethine-H. *Can.J.Soil Sci.* **59**, 241-247.

Gupta, U.C. (1993) Boron and its role in crop production. CRC Press. Boca Raton, Florida, USA.

Heaney, D.J.,McGill, W.B. & Nguyen, C. (1988) Soil test quality assurance program, final report. Alberta Institute of Pedology, Edmonton, Alberta, Canada.

Hendershot, W.H & Duquette, M (1986) A simple barium chloride method for determining cation exchange capacity and exchangeable cations. *Soil Sci. Soc. Am.* J. **50**, 605-608.

Hodgins, L.W.& Karamanos, R.E. (1992) Sources of variation in soil testing. Paper presented at the Soils and Crops Workshop, February 20-21, 1992, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Hogan, G.D. & Maynard, D.G. (1984) Sulphur analysis of environmental materials by vacuum inductively coupled plasma atomic emission spectrometry (ICP-AES). pages 676-683 *In* Proc. Sulphur-84, Int. Conf., Calgary, Alberta, June 1984. Sulphur Dev. Inst. Can., Calgary, Alberta, Canada.

Houba, V.J.G., Uittenbogaard, J & Pellen, P.J. (1993) International Soil-analytical Exchange (ISE). Department of Soil Science and Plant Nutrition. Wageningen Agricultural University, Wageningen, the Netherlands.

Hoyt, P.B. & Nyborg, M (1972) Use of dilute calcium chloride for the extraction of plant available aluminium and manganese from acid soil. *Can. J. Soil Sci.* **52**, 163-167.

Janzen, H.H &Chang, C. (1988) Cation concentrations in the saturation extract and soil solution extract of soil salinized with various sulfate salts. *Commun. Soil Sci. Plant Anal.* **19**, 405-430.

Jones, J.B., Jr & Kalra, Y.P. (1992) Soil testing and plant analysis activities- the United States and Canada. *Commun. Soil Sci. Plant Anal.*, **23**, 2015-2027.

Juma, N.G., Paul, E.A. & Mary, B (1984) Kinetic analysis of net nitrogen mineralization in soil. *Soil Sci. Soc. Am J.* **48**, 753-757.

Kalra, Y.P. (1971) Methods used for soil, plant, and water analysis at the soils laboratory of the Manitoba-Saskatchewan region, 1967-1970. Environ. Can., Can. For Serv., North. For. Res. Cent., Edmonton, Alberta, Canada. Inf. Rep. NOR-X-11.

Kalra, Y.P. (1977) Application of atomic absorption spectrophotometry in soil, plant, water and fertilizer analysis: an annotated bibliography. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta, Canada. File Rep. 6935-2.

Kalra, Y.P. (1993a) AOAC INTERNATIONAL/ Soil Science Society of America collaborative study on pH measurements in soil. Paper presented at the Soil and Environmental Chemistry Workshop, AOAC INTERNATIONAL Pacific Northwest Region Section; June 24-25, 1993, Olympia, Washington, USA.

Kalra, Y.P (1993b) Soil and plant analysis in Canada. Paper presented at the International Symposium on Soil Testing and Plant Analysis: Precision Nutrient Management. Soil and Plant Analysis Council; August 14-19, 1993. Olympia, Washington, USA.

Kalra, Y.P. (1994) pH measurements in soil: AOAC INTERNATIONAL/ Soil Science Society of America procedures update. Paper presented at the Soil and Environmental Chemistry Workshop, AOAC INTERNATIONAL Pacific Northwest Region Section, June 22-23, 1994, Olympia, Washington, USA.

Kalra, Y.P. & Ali, M.W. (1970) Operation of the service laboratory at the Manitoba-Saskatchewan region. Can. For Serv., Dep. Fish. For., Nor. For. Res. Cent., Edmonton, Alberta, Canada, Int. Rep. A-39.

Kalra, Y.P. & Edwards, I.K. (1974) Possible sources of errors in chemical analyses of IUFRO plant samples. *IUFRO News*, **7**, 10-11.

Kalra, Y.P. & Edwards, I.K. (1982) Evaluation of extractants for the determination of available Mn in forest-nursery soils. page 85 *in* Abstracts. *Trans. 12th Int. Cong. Soil Sci.*, February 8-16, 1982. New Delhi, India.

Kalra, Y.P., Koteles, G.J., Morrison, I.K. & Ramakers, J.R. (1994) Forestry Canada's interlaboratory study for the analysis of plant materials. *Commun. Soil Sci. Plant Anal* **25**, 1517-1525.

Kalra, Y.P & Maynard, D.G. (1986) An evaluation of automated and manual methods for NH_4-N analysis in the determination of cation exchange capacity of soils. pp 67-76, *in* L.K. Pleijsier, editor. Proceedings of an Internatioanl Workshop on the Laboratory Methods and Data Exchange Programme; August 25-29, 1986, Int. Soil Ref. Inf. Cent., Wageningen, the Netherlands.

Kalra, Y.P & Maynard, D.G. (1987) Northern Forestry Centre's participation in soil and plant check sample programs. pp 4-5 *in* Pac. Reg. Soc. Soil Sci. News 14, University of British Columbia, Vancouver, British Columbia, Canada.

Kalra, Y.P. & Maynard, D.G (1990) An evaluation of a mechanical vacuum extractor for the determination of cation exchange capacity and extractable cations in calcareous soils. Vol. II: Comm II, pp 451-452. In *Trans. 14th Int. Cong. Soil Sci.* August 12-18, 1990, Kyoto, Japan.

Kalra Y.P. & Maynard, D.G. (1991). Methods manual for forest soil and plant analysis. For Can., Northwest Reg., North. For. Cent., Edmonton, Alberta, Canada. Inf. Rep. NOR-X-319.

Kalra, Y.P. & Maynard, D.G. (1994) A comparison of extractants for the determination of cation exchange capacity and extractable cations by a mechanical vaccum extractor. *Commun. Soil Sci. Plant Anal.* **25**, 1505-1515.

Kalra, Y.P., Maynard, D.G. & Radford, F.G. (1989) Microwave digestion of tree foliage for multi-element analysis. *Can. J. For. Res.* **19**. 981-985.

Kalra, Y.P., Maynard,D.G. & Radford, F.G. (1990) Digestion of tree foliage by microwave for analysis by

ICP-AES. Paper presented at the Soil and Plant Analysis Workshop of the AOAC INTERNATIONAL Pacific Northwest Regional Section; June 21-22, 1990. Olympia, Washington, USA.

Kalra, Y.P. & Peters, M.K. (1981) WEALA check soil sample program: a collaborative study. Western Enviro-Agricultural Laboratory Association, Edmonton, Alberta, Canada. Rep. WEALA-1

Kalra, Y.P. & Radford, F.G(1975) Suitability of ammonium EDTA extraction procedure for dertermining calcium in tree foliage. *Comm. Soil Sci. Plant Anal.* **6**, 13-19.

Karamanos, R.E., Kruger, G.A. & Henry, J.L. (1992) Fertility Analysis and Recommendations Manager (F.A.R.M) Paper presented at the Soils and Crops Workshop; February 20-21, 1992. University of Saskàtchewan, Saskatoon, Saskatchewan, Canada.

Kay, B.D., Grant, C.D & Groenevelt, P.H. (1985) Significance of ground freezing on soil bulk density under zero tillage *Soil Sci. Soc. Am. J.* **49**, 973-978.

Khan, S.U & Webster, G.R. (1968) Determination of gypsum in solonetzic soils by an X-ray technique. *Analyst,* **93**, 400- 402.

Kimpinski, J & Welch, H.E. (1971) Comparison of Baermann funnel and sugar flotation extraction from compacted and non-compacted soils. *Nematologica,* **17**, 319-320.

Kjeldahl, J. (1883) Neue methode zur bestimmung des stickstoffs in organischen korpern. *Z. Anal. Chem.* **22**, 366-382.

Kodama, H., Scott, G.C& Miles, N.M. (1977) X-ray quantitative analysis of minerals in soils. Soil Research Institute, Ottawa, Canada.

Konard, J.M. (1987) Procedure for determining the segregation potential of freezing soils *Geotech Test J.* **10**, 51-58

Kowalenko, C.G. (1985) A modified apparatus for quick and versatile sulphate sulphur analysis using hydriodic acid reduction. *Commun. Soil Sci. Plant Anal.* **16**, 289-300.

Kowalenko, C.G. (editor) (1993) Soil test analysis methods for British Columbia agricultural crops. British Columbia Ministry of Agriculture, Fisheries and Food, Victoria, British Columbia, Canada.

Kratochirl, B (1992) Sampling for chemical analysis. pp 8-1 to 8-31 *In* S. Abboud (editor) .Proceedings of the 4th Annual WEALA Workshop on Heavy Metals in the Environment. Western Environmental Agricultural Laboratory Association;April 28, 1992. Edmonton, Alberta, Canada.

Laverty, D.H. & Bollo-Kamara, A (1988) Recommended methods of soil analysis for Canadian prairie agricultural soils. Alberta Agriculture, Edmonton, Alberta, Canada.

Lavkulich, L.M. (1981) Methods manual, pedology laboratory. Department of Soil Science, University of British Columbia, Vancouver, British Columbia, Canada

Lowe, L.E & DeLong, W.A. (1963) Carbon bonded sulphur in selected Quebec soils *Can. J. Soil Sci.* **44**, 66-75.

Mahendrappa, M.K. & Kingston, D.G.O. (1991) The lysimeter studies in the Martitimes Region. Paper presented at the Canadian Society of Soil Science Annual Meeting; July 29-31, 1991, Fredericton, New Brunswick, Canada.

Malhi, S.S., Nyborg, M. & Solberg, E.D (1989) Recovery of N- labelled areas as influenced by straw addition and method of placement. *Can. J. Soil Sci.* **69**, 543-550.

Mathur, S.P. & Levesque, N.P (1988) Soil tests for copper, iron, manganese, and zinc in Histosols. 2. The distributions of soil iron and mangaenese in sequentially extractable forms *Soil Sci.* **145**, 102-110.

Maynard, D.G. (1990) Biomonitoring forests near two sour gas processing plants. For. Can. Northwest Reg., North For. Cent., Edmonton, Alberta, Canada. Inf. Rep. NOR-X-311.

Maynard, D.G.& Addison, P.A (1985) Extraction and colorimetric determination of elemental sulfur in organic horizons of forest soils. *Can.J. Soil Sci.* **65**, 811-813.

Maynard, D.G.& Kalra Y.P. (1993) Nitrate and exchangeable ammonium nitrogen. pp 25-38 *In* M.R. Carter, editor. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida, USA.

Maynard, D.G., Kalra, Y.P. & Radford, F.G (1987) Extraction and determination of sulfur in organic horizons of forest soils. *Soil Sci Soc. Am. J.* **51**, 801-806.

Maynard, D.G., Stadt, J.J., Mallet, K.I. & Volney, W.J.A. (1994) *Biomonitoring forest health in west-central* Alberta. Inf. Rep. NOR-X-334.

Maynard, D.G., Stadt, J.J, Mallet, K.I., Volney, W.J.A. & McCoy, D (1993) Biomonitoring forest health in lodgepole pine of west central Alberta. Paper presented at the 86th Annual Meeting and Exhibition of the Air and Waste Management Association; June 13- 18 1993. Denver, Colorada, USA.

McGill, W.G., Shields, J.A. & Paul, E.A. (1975) Relation between carbon and nitrogen turn-over in soil organic fractions of microbial origin. *Soil Biol. Biochem.* **7**, 57-63.

Mckeague, J.A. (editor) (1978) Manual on soil sampling and methods of analysis. *Can. Soc. Soil. Sci.* Ottawa, Ontario, Canada.

McKeague, J.A., Sheldrik, B.H. & Desjardins, J.G. (1978) Compilation of data for CSSC reference soil samples. Agric. Can., Soil Res. Int., Ottawa. Ontario, Canada.

McBride, R.A. & Bober, M.L. (1989) A re-examination of alternative test procedure for soil consistency limit determination. I.A. compression-based procedure. *Soil Sci. Soc. Am. J.* **53**, 178-183.

Morries, P (1983) A century of Kjeldahl (1883-1983). *J. Assoc. Public Analysts,* **21**, 53-58.

Naidia, A. & Huang, P.M. (1992) Deamination of aspartic acid by aspartase immobilized on Ca^{2+} montmorillonite. Paper presented at the International Society of Soil Science Working Group MO, First Workshop. Impact of Interactions of Inorganic, Organic, and Microbiological Soil Components on Environmental Quality; August 11-15, 1992, Edmonton, Alberta Canada.

Neilsen, G.H., Hoyt, P.B & Hogue, E.J. (1989) Identification of K deficiency in British Columbia apple orchards. *Can. J. Soil Sci.* **69**, 715-719.

Neufeld, J.H. (1980) Soil testing methods and interpretations. British Columbia Ministry of Agriculture, Kelowna, British Columbia, Canada Publ. 80-2.

Olsen, P.E., Rice, W.A., Stemke, G.W & Page, W.J. (1983) Strain- specific serological techniques for identification of *Rhizobium meliloti* in commercial alfalfa inoculants. *Can. J. Microbial.* **29**, 225-230.

Parent, L.E., Fanous, M.A. & Millette, J.A. (1982) Comments on parametric test limitations for analyzing data on peat decomposition. *Can J. Soil Sci.* **62**, 545-547.

Parent, L.E., Pauze, F.J & Bourbeau, G.A. (1980) Methode nouvelle de preparation de coupes minces des tourbes et des gyttja. *Can. J. Soil Sci.* **60**, 487-496.

Pawluk, S. (1967) Soil analyses by atomic absorption spectrophotometry. *Atom. Absorp. News.* **6**, 53-56.

Pleijsier, L.K. (1985) The laboratory methods and data exchange programme: Interim report on the exchange round 85-1. Int. Soil Ref. Inf. Cent., Wageningen, the Netherlands.

Qian, P. Schoenau, J.J.& Huang, W.Z. (1992) Determining the available nutrient status of soil using ion exchange membrane extraction and burial. Paper presented at the Environmental Soil Science Conference, sponsored jointly by Canadian Land Reclamation Association and Canadian Society of Soil Science; August 8-13, 1992. Edmonton, Alberta, Canada.

Rennie, P.J. (1966) The use of micropedology in the study of some Ontario podzolic profiles. *J. Soil Sci.* **17**, 99-106.

Rennie, R.J. (1981) A single medium for the isolation of acetylene-reducing (dinitrogen-fixing) bacteria from soils, *Can. J. Microbiol.* **27**, 8-14.

Reynolds, W.D & Elrick, D.E. (1991) Determination of hydraulic conductivity using a tension infiltrometer. *Soil Sci. Soc. Am. J.* **55**, 633-639.

Reynolds, W.D., Elrick, D.E.& Topp, G.C. (1983) A reexamination of the constant head well permeameter method for measuring saturated hydraulic conductivity above the water table, *Soil Sci.* **136**, 250-268.

Richards, J.E. & Bates, T.E. (1988) Studies on the potassium supplying capacities of Southern Ontario soils. II. Nitric acid extraction of the non-exchangeable K and its availability to crops. *Can. J. Soil Sci.* **68**, 199-208.

Roberts, T.L., Bettany, J.R. & Stewart, J.W.B (1989) A hierarchical approach to the study of organic C, N, P and S in western Canadian Soils. *Can. J. Soil Sci.* **69**, 739-750.

Robertson, J.A. (1962) Comparison of an acid and an alkaline extracting solution for measuring available phosphorus in Alberta soils. *Can J. Soil. Sci.* **42**, 115-121.

Ross, G.J., Schuppli, P.A. & Wang, C. (1989) Quantitative determination of vermiculite by a rubidium fixation method. *Soil Sci. Soc. Am. J.* **53**, 1588-1589.

Saggar, S., Bettany, J.R. & Stewart, J.W.B. (1981) Measurement of microbial sulfur in soil. *Soil Biol. Biochem.* **13**, 493-498.

Schnitzer, M. & Schuppli, P. (1989) The extraction of organic matter from selected soils and particle size fractions with 0.5 *M* NaOH and 0.1 *M* $Na_4P_2O_7$ solutions. *Can. J. Soil Sci.* **69**, 253-262.

Schoenau, J.J. & Bettany, J.R. (1987) Organic matter leaching as a component of carbon, nitrogen, phosphorus, and sulfur cycles in a forest, grassland, and gleyed soil. *Soil Sci. Soc. Am. J.* **51**, 646-651.

Sheldrick, B.H. (editor) (1984) Analytical methods manual 1984. Agric Can., Land Resour. Inst., Res. Branch, Ottawa, Ontario, Canada, Contrib. 84-30.

Sheldrick, B.H. (1986) Quality control procedure, precision, and rate of analysis in the analytical laboratory. Agric Can, Land Resour. Res. Cent., Res. Branch, Ottawa, Ontario, Canada. Contrib. 85-69.

Sheldrick, B.H. & Wang, C (1987) Compilation of data for ECSS (Expert Committee on Soil Survey) reference soil samples. Land Resour. Res. Cent., Branch, Ottawa, Ontario, Canada.

Sidhu, S.S. & Feng, J.C.(1993) Hexazinone metabolites in boreal vegetation. *Weed Sci.* **41**, 281-287.

Simard, R.R & Deschenes, M. (1992) Strontium chloride-citric acid extraction procedure for agricultural and environmental purposes. *Commun. Soil Sci. Plant Anal.* **23**, 2207-2223.

Singh, S.S & Brydon, J.E. (1969) Solubility of basic aluminum sulfates at equilibrium in solution and in the presence of montmorillonite. *Soil Sci.* **107**, 12-16.

Singh, T. & Kalra, Y.P. (1975) Specific conductance method for *in situ* estimation of total dissolved solids. *J. Am.Wat. Works Assoc.* **67**, 99-100.

Skinner, S.I.M. & Halstead, R.L. (1958) Note on rapid method for determination of carbonates in soils. *Can. J. Soil Sci.* **38**, 187-188.

Skinner, S.I.M., Halstead, R.L. & Brydon, J.E. (1959) Quantitative manometric determination of calcite and dolomite in soils and limestones. *Can. J. Soil Sci.* **39**, 97-204.

Soon, Y.K. (1992) Extraction of trace elements from soils, especially heavy metals: Considerations and comaprison of methods for agricultural and environmental soil testing. Pages 4-1 to 4- 10 *In* S. Abboud, editor. Proceedings of the 4th Annual WEALA Workshop on Heavy metals in the environment. Western Enviro-Agricultural Laboratory Association; April 28, 1992. Edmonton, Alberta, Canada.

Spinks, J.W.T. & Barber, S.A. (1947) Study of fertilizer uptake using radioactive phosphorus. *Sci. Agric.* **27**, 145-156.

Stewart, J.W.B. & Tissen, H. (1987) Dynamics of soil organic phosphorus. *Biochemistry.* **4**, 41-60.

Subramanian, K & Iyengar, V (1994). Low level environmetnal lead: Need for reference materials. Paper presented at the 6th International Symposium on Biological and Environmental Reference Materials. Topical Conference of AOAC INTERNATIONAL Technical Division on Reference Materials; April 17-21, 1994. Kailua-Kona, Hawaii, USA.

Szmigielska, A.M., Van Rees, K.C.L., Cieslinski, G., Huang, P.M. & Knott, D (1994) Determination of low molecular weight dicaroboxylic acids in root exudates by a gas chromotagraphy. Paper presented at the Annual Meeting of the Canadian Society of Soil Science; July 10-13, 1994. Regina, Sadkatchewan, Canada.

Tel, D.A. (1989a) An automated procedure for the determination of boron in 0.4 *N* HCl plant extract. Unpublished method. Department of Land Resource Science, University of Guelph, Ontario, Canada.

Tel, D.A. (1989b) Ammonia in soil and plant extracts, water and waste water. Technicon TRAACS 800

Industrial Method No. 780-89T. Technicon Instruments Corporation, Tarrytown, New York, USA.

Tel, D.A. & Covert, J.A (1992) Determination of phenolic acids and tannins in soil water extracts using the Technicon Auto Analyzer II system. *Commun. Soil Sci. Plant Anal.* **23** 2737- 2747.

Tel, D.A., Liu, L & Shelp, B.J. (1992) Determination of total nitrogen in plant digests using a TRAACS 800 AutoAnalyzer. *Commun. Soil Sci. Plant. Anal.* **23**, 2771-2779.

Tiessen, H., Bettany, J.R.& Stewart, J.W.B. (1981) An improved method for the determination of carbon in soils and soil extracts by dry combustion. *Commun. Soil Sci. Plant. Anal.* **12**, 211- 218.

Toogood, J.A. & Peters. T.W. (1953) Comparison of methods of mechanical analysis of soils *Can. J. agric. Sci.* **33**, 159-171.

Topp, G.C. Davis, J.L., Bailey, W.G & Zebchuk, W.D. (1984) The measurement of soil water content using a portable TDR hand probe. *Can. J. Soil Sci.* **64**, 313-321.

Tran, T.S. & Giroux, M. (1985) Disponibilite du phosphore dans les sols neutres et calcaires du Quebec en relation avec les proprietes chimiques et physiques. *Can. J. Soil Sci.* **67**, 1-16.

Turner, R.C. (1960) An investigation of the intercept method for determining the proportion of dolomite and calcite in mixtures of the two. I. Theoretical aspects of the rate of solution of dolomite when a number of crystals are present. *Can. J. Soil Sci.* **40**, 219-231.

Turner, R.C & Skinner S.I.M (1960) An investigation of the intercept method for determining the proportion of dolomite and calcite in mixtures of the two. II. Experimental rates of soultion of dolomite and calcite in samples consisting of a number of crystals. *Can J. Soil Sci.* **40**, 232-241.

van Goor, C.P. (1978). The comparability of results of chemical analysis of leaf samples. Final report of IUFRO Working Party 3. For. Res. Stn. De Dorschkamp, Wageningen, the Netherlands.

van Goor, C.P., de Wit, M. & van den Burg, J (1971) International comparison of methods for soil and plant analysis. Report of activities in 1970. For Res. Stn. De Dorschkamp, Wageningen, the Netherlands.

van Lierop, W. (1989) Effect of assumptions on accuracy of analytical results and liming recommendations when testing a volume or weight of soil. *Commun. Soil Sci. Plant Ananl.* **30**, 121-137.

van Lierop, W & Gough, N.A. (1989) Extraction of potassium and sodium from acid and calcareous soils with the Kelowna multiple element extraction. *Can. J. Soil Sci.* **69**, 235-242.

Voroney, R.P.& Paul E.A (1984). Determination of K_c and K_n *in situ* for calibration of the chloroform fumigation incubation method. *Soil Biol. Biochem.* **16**, 9-14.

Walker, D.R. & Bentley, C.F. (1961) Sulphur fractions of legumes as indicators of sulfur deficiency. *Can. J. Soil Sci.* **41**, 164-168.

Wang, C. Schuppli, P.A. & Ross, G.J (1987) A comparison of hydroxylamine and ammonium oxalate solutions as extractants for Al, Fe and Si from Spodosols and Spodosol-like soils in Canada. *Geoderma.* **40**, 345-355.

Warkentin, B.P. & Bozozuk, M. (1961) Shrinking and swelling properties of two Canadian clays. pp 851-855 *in* Vol. 3A/49 of the Proc. 5th Int. Conf. Soil Mech. Found. Eng.; July 17-27, 1961, Paris France.

Webber, M.D. (1972) A comparison of ignition treatments for Pb measurement in plant tissues. *Can. J Soil Sci.* **52**, 282-284.

Webber, M.D. (1974) Atomic absorption measurements of Al in plant digests and neutral salt extracts of Soil. *Can. J. Soil Sci.* **54**, 81-87.

Williams, P.J. & Smith, M.W. (1989) The frozen earth. Fundamental of Geocryology. Cambridge University Press, Cambridge, United Kingdom.

Zoltai, S.C. (1978) A portable sampler for perenially frozen stone-free soils. *Can. J. Soil. Sci.* **58**, 521-523.

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