4.0 RESULTS AND DISCUSSION

The literature search yielded 52 environmental monitoring programs that met the search criteria. The term “program” is used to describe both entire programs and separate parts of a monitoring program. The search revealed environmental monitoring programs which did not include the repeated monitoring of any soil properties. Others had not resampled any soil properties since the program was established. An example of this is the National Resources Inventory (NRI) in the United States of America. This program monitors over 800,000 sample points across the entire nation but does not monitor soil on a regular basis (53). Many long-term monitoring programs, which imposed agronomic treatments were also found. For example, in Alberta alone, there are six long-term, small plot, sustainable cropping systems studies which 1) determine crop productivity and soil quality effects in accordance with established research protocols and 2) determine the capacity of Alberta agroecosystems to sequester atmospheric carbon. Although programs of this type are valuable in identifying profitable and sustainable agricultural systems and may provide supplemental information for monitoring programs, they impose agronomic treatments and therefore do not meet the criteria set out for this literature review.

A majority of the references are “grey” or unpublished literature found on web pages and in institutional reports. This poses a problem because the documents referenced may become unavailable or outdated in a short time frame. Dramstad et al. (2002) also experienced difficulties finding documentation because a large portion of information about certain monitoring programs is located in non-English language institutional reports. An analysis of the literature cited finds that 35% are web pages or electronic citations, 20% are conference proceedings, 16% are reports, 11% are refereed journal articles, while the remainder are from magazine articles, books, emails, dissertations and poster presentations.

Programs that met the criteria were researched further and the program details were summarized (Tables 2 and 3). The information collected in Table 2 includes:

- country or organization responsible for the monitoring program
- program title
- program management
- program lifespan
- objectives or purpose of monitoring
- type of ecosystem and components measured
- spatial variability of sampling points
- sampling interval and methods
- program costs
- data dissemination
- data trends

In many instances, a complete program description was not available. Blank cells in Table 2, with the exception of the “End Date” column, indicate no information was provided in the reviewed documentation or the category was not applicable. The “End Date” column includes text only if the program was terminated, otherwise the program is assumed to be operational. The programs were grouped into continents or networks, organized by alphabetical order and were then given numbers (column labeled “Prog No.”). The numbers facilitate referencing the programs in the document and in displaying the information in tables. Bibliographic references appear as numbers in the “References” column of the table and are recorded in ProCite version 5 for Windows (ISI ResearchSoft, Philadelphia, Pennsylvania, USA) The numbers correspond to the same number listed in section 6.0, the “Literature Cited” section of this document.

Selected parameters measured by each program are included in Table 3. The ten parameters are:

- soil test analysis
- chemical
- physical
- biological
- biochemical
- micronutrients
- pollutants
- management information
- site description
- climatic data

Some programs measured other parameters related to air, water and biota, which were not the focal point of this review and were excluded. A “yes” in the table indicates the parameter was measured or is pertinent. Blank cells in the table, indicate no information was provided in the reviewed documentation or the category was not applicable.

Additional program details are provided in section 7.0, the “Appendix” of this document.

Table 2. Monitoring program descriptions – Part 1

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
NORTH AMERICA						
1	Alberta	AESA Soil Quality Benchmark Program	Alberta Environmentally Sustainable Agriculture Program-Alberta Agriculture, Food and Rural Development	1998		- provide baseline soil information, evaluate landscape effects on soil quality, provide data for modeling and monitor changes in soil quality over time
2	Alberta	Long-Term Soil and Vegetation Plots Established in the Oil Sands Region	Syncrude Canada/ Suncor Energy/ Albian Sands/ Cumulative Environmental Management Association	2000		- initial purpose was to determine forestry success and meet equivalent productivity with reclaimed sites - now more focus on the importance of biodiversity and the value of understory
3	Canada	Soil Quality Benchmark Sites	Agriculture and Agri-Food Canada	1992		- assess soil quality change, provide validation for models, provide well documented sites for future integrated research programs and evaluate sustainability
4	United States of America	Forest Health Monitoring Program (1990-1999) / Forest Inventory and Analysis Program (1999-present)	USDA Forest Service / Environmental Protection Agency / USDA Bureau of Land Management / USDA Natural Resource Conservation Service	1990		- determine the status, changes and trends in indicators of forest health on an annual basis - identify important forest health and sustainability issues, select appropriate data and develop approaches to address the issues
EUROPE						
5	Albania	Map of Soils of Albania	Soil Science Institute of Tirana			
6	Austria	Forest Soil Monitoring System	Federal Forest Research Centre	1987		- originated as part of the Forest Damage Monitoring System to research causes and effects of forest diebacks
7	Bulgaria	Background Monitoring	Bulgarian Executive Environmental Agency			- background monitoring of atmosphere, precipitation, surface water, soil and vegetation
8	Bulgaria	National Environment Monitoring System	Bulgarian Executive Environmental Agency			
9	Czech Republic	Basal Soil Monitoring Scheme	Ministry of Agriculture / Ministry of Environment	1992/ 1993		- characterize the status of soils, observe changes in soil as a result of human activity, test new analytical methods and develop new strategies/standards of soil protection and prevention
10	Denmark	Heavy Metal Monitoring Programme	Danish Environmental Protection Agency	1993		- statistically safe detection of a 2% increase in the mean concentration of heavy metals in soils

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
11	England and Wales	National Soil Inventory	National Soil Resources Institute	1978-1983/ 1994-1996		- provide information on the range of concentrations of pollutants, nutrients, soil organic matter and pH in soils of England and Wales
12	England and Wales	Annual Representative Soil Sampling Scheme	Ministry of Agriculture, Fisheries and Food / Agricultural Development and Advisory Service	1969		- provides an estimate of the status of agricultural soils in relation to changes in agricultural practices
13	Finland	National Forest Inventory	Finnish Forest Research Institute	1921		- to produce objective and up to date information on forest resources, forest health conditions and their development for national and regional decision making
14	Finland	Soil Quality Monitoring Program		1992		
15	France	Soil Quality Observatory	Ministry of Environment / Ministry of Agriculture / French Environmental Institute / National Institute of Agronomic Research	1986		- assess the present situation of soils, monitor their changes and identify the causes to improve on and implement a soil preservation policy - provide data for modeling and increase soil quality awareness
16	France	RENECOFOR	National Forest Office	1992		- help detect long-term changes is a wide variety of ecosystems and determine the cause of those changes
17	Germany	Permanent Soil Monitoring Sites		1986		- to investigate how soils change due to anthropogenic involvement
18	Germany	Air Measuring Network	Federal Environmental Agency			- registration of extensive emission loads caused by air pollutions, including depositions - determine influence of air pollution on soil quality
19	Great Britain	Country-side Survey		1978/ 1984/ 1990/ 1998		- estimate extent and characterize habitats, derive sustainable development indicators and provide data and databases
20	Hungary	Information and Monitoring System of Soil Conservation (TIM) - National Basic Monitoring System	Ministry of Agriculture / Plant Protection and Soil Conservation Service	1992		- to provide information for scientifically based planning and implementation of sustainable land use and rational soil management

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
21	Hungary	Information and Monitoring System of Soil Conservation (TIM) - Forestry Observation Points	Ministry of Agriculture / Plant Protection and Soil Conservation Service	1992		- to provide information for scientifically based planning and implementation of sustainable land use and rational soil management
22	Hungary	Information and Monitoring System of Soil Conservation (TIM) - Special Areas Monitoring	Ministry of Agriculture / Plant Protection and Soil Conservation Service	1992		- to provide information for scientifically based planning and implementation of sustainable land use and rational soil management
23	Hungary	Soil Fertility Monitoring System		1978	1986	- monitor changes in soil parameters and make recommendations on nutrient supply to farmers
24	Hungary	Microelement Survey		1987	1990	
25	Latvia	National Agricultural Land Monitoring Programme	State Land Service	1992	2000/ 2001	- supervise process and trends of soil quality changes, gather information, make interpretations and report regularly to the public and decision makers - long-term observations of anthropogenic impacts on agricultural land
26	Lithuania	National Environmental Monitoring Programme - Field Soil Monitoring	Agrochemical Research Centre of the Lithuanian Institute of Agriculture / Joint Research Centre of the Ministry of the Environment	1993		Soil monitoring component: to analyze and explain the development of qualitative and quantitative processes, to forecast and control anticipated processes and to identify the means for prevention of loss of soil stability
27	Lithuania	National Environmental Monitoring Programme - Forest Soil Monitoring	Lithuanian Forestry Institute	1992		Soil monitoring component: to analyze and explain the development of qualitative and quantitative processes, to forecast and control anticipated processes and to identify the means for prevention of loss of soil stability
28	Lithuania	National Environmental Monitoring Programme - Integrated Monitoring of Agricultural Ecosystems	Lithuanian Water Management Institute / Institute of Ecology / Agrochemical Research Centre of Lithuanian Agricultural Institute / Institute of Botany / Institute of Geography			- to determine, assess and forecast the status of ecosystems subjected to intense agricultural activities and its changes in time with consideration of the type of farming practices
29	Netherlands	National Soil Quality Monitoring Network	National Institute of Public Health and Environmental Protection (RIVM)	1993		- establish changes in soil quality over time in soil and upper groundwater - determine actual quality of soil and upper groundwater with a focus on the rural environment
30	Netherlands	Regional Soil Quality Monitoring Networks	individual provinces of the Netherlands	1991		- provide insight into geo-chemical soil quality trends on which to base new provincial policies

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
31	Netherlands	Soil Quality and Shallow Ground Water Monitoring	National Institute of Public Health and Environmental Protection (RIVM)	1992		- assess the vulnerability of agricultural soils and ground-water to pollutants such as manure and artificial fertilizers
32	Norway	Agricultural Environmental Monitoring Program	Ministry of Agriculture / Ministry of Environment	1992		- to relate losses of plant nutrients to catchment characteristics and changes in agricultural practices
33	Poland	National Program of Environment Monitoring	Ministry of Agriculture and Food Economy	1994		- to perform a detailed evaluation of existing resources in order to identify areas of high risk to the food chain
34	Poland	Arable Soils Monitoring Program	Ministry of the Environment	1995	1998	
35	Poland	Programme for Forest Monitoring		1989		- to monitor environmental threats to the forest ecosystem such as atmospheric pollution
36	Republic of Estonia	Estonian Environmental Monitoring Program - Agricultural Landscape Monitoring	Estonian Environment Information Centre	1996		- monitor long-term and large-scale changes in environment, identify problems which need countermeasures and future research - to define changes in land use and assess the anthropogenic impact on ecological status of soil
37	Romania	National Integrated Soil Monitoring System	Research Institute for Soil Science and Agrochemistry	1992		- to identify problem areas, causes of problems and possible remedial actions
38	Slovakia	Slovak Environment Monitoring	Ministry for the Environment / Ministry of Landhusbandry	1993		- reflect the environmental situation and apply measures for environmental improvement
39	Slovakia	Slovak Environment Monitoring - Soil Monitoring System- Humus	Soil Science and Conservation Research Institute	1993		- to monitor soil contamination and soil properties
40	Sweden	National Swedish Environmental Monitoring Programme - Integrated Monitoring	Swedish Environmental Protection Agency	1981		- regular and permanent recording of environmental conditions and long-term changes in background regions - to track the flux of pollutants in and between various media
41	Sweden	National Swedish Environmental Monitoring Programme - National Survey of Forest Soils and Vegetation	Department of Forest Resource Management and Geomatics / Swedish University of Agricultural Sciences	1983		- describe the state of and changes in forest resources of Sweden

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
42	Sweden	National Swedish Environmental Monitoring Programme - Agricultural Land Programme Area	Department of Soil Sciences- Swedish University of Agricultural Sciences			- quantify variations in time and space regarding concentrations and transported amounts of nutrients and pesticides in surface and groundwater whose catchment areas are dominated by agriculture
43	Switzerland	Swiss Soil Monitoring Network	Swiss Agency for the Environment, Forests and Landscape / Swiss Federal Office for Agriculture / Swiss Federal Research Station for Agroecology and Agriculture	1985		- scientific validation and evaluation of the success of environmental policy measures aiming long-term conservation of soil fertility
NEW ZEALAND						
44	New Zealand	Implementing soil quality indicators for land - "500 Soils Project"	Ministry for the Environment Sustainable Management Fund / Landcare Research	1998	2001	- to determine the effects of land use on soil quality and integrate the data from regions into a national overview
ICP						
45	United Nations Economic Commission for Europe	UN-ECE ICP Integrated Monitoring of Air Pollution Effects on Ecosystems	UN/ECE Working Group on Effects/ Sweden / ICP IM Programme Centre	1993		- long-term international ecosystem monitoring program to predict the state of and possible medium to long-term changes in natural ecosystems caused by trans-boundary air pollutants
46	United Nations Economic Commission for Europe	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests - ICP Forests Level 1	UN/ECE Working Group on Effects / Task Force of ICP Forests / Programme Coordinating Centre	1986		- monitor the effects of anthropogenic and natural stress factors on the condition and development of forest ecosystems in Europe - contribute to a better understanding of cause-effect relationships in forest ecosystem functioning
47	United Nations Economic Commission for Europe	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests - ICP Forests Level 2	Forest Intensive Monitoring Coordinating Institute	1994		- monitor the effects of anthropogenic and natural stress factors on the condition and development of forest ecosystems in Europe - contribute to a better understanding of cause-effect relationships in forest ecosystem functioning
Networks						
48	United Kingdom	Environmental Change Network	Natural Environment Research Council	1994		- detection, interpretation and forecasting of environmental changes resulting from natural and anthropogenic causes
49	International	Terrestrial Ecosystem Monitoring Sites	Global Terrestrial Observing System	1995		- database on terrestrial ecosystem monitoring sites which registers sites and networks carrying out long-term terrestrial monitoring

Prog. No.	Country/ Org.	Program Title	Management / Funding	Start Date	End Date	Purpose
50	International	International Long-Term Ecological Research Network	Global Terrestrial Observing System	1993		- promote and encourage long-term ecological research, exchange of data, produce comparable results and facilitate development of other programs
51	Pan-European	Networking of Long-term Integrated Monitoring in Terrestrial Systems - NoLIMITS	European Network for Research in Global Change	future		- facilitate and co-ordinate the exchange and integration of environmental data between other monitoring networks, further scientific research and implement sustainable development policy
52	Europe	proposed European Soil Monitoring Network (EuroSoilNet)	European Commission Directorate General Joint Research Centre	future		- provide policy relevant information on the major threats to soil in Europe in a harmonized and coherent way

Table 2. Monitoring program descriptions – Part 2

Prog. No.	Components Measured: Soil	Air	Water	Biota	Site Type: Agricultural	Forested	Natural	Other	Soil Type
NORTH AMERICA									
1	yes			yes	yes				agricultural soils across Alberta
2	yes			yes		yes		reclaimed	
3	yes			yes	yes				agricultural soils across Canada
4	yes	yes	yes	yes		yes			
EUROPE									
5	yes				yes				
6	yes			yes		yes			
7	yes	yes	yes	yes					light brown, high mountainous, sand-clay
8	yes	yes	yes	yes				pollution areas	
9	yes			yes	yes			protected areas	
10	yes				yes			sewage sludge areas	
11	yes				yes	yes	yes	open lands	
12	yes				yes				
13	yes			yes		yes			
14	yes				yes				
15	yes				yes	yes	yes		
16	yes	yes	yes	yes		yes			
17	yes				yes	yes		municipal	
18	yes	yes							
19	yes		yes	yes	yes			open lands	
20	yes		yes		yes				
21	yes		yes			yes			
22	yes		yes					threatened	
23	yes			yes	yes				
24	yes				yes				
25	yes			yes	yes				20 soil types
26	yes				yes				15 soil regions

Prog.	Components Measured				Site Type				Soil Type
No.	Soil	Air	Water	Biota	Agricultural	Forested	Natural	Other	
27	yes					yes			
28	yes		yes	yes	yes				
29	yes		yes		yes	yes			10 land types
30	yes		yes		yes	yes	yes	greenhse/bulb/orchard	peaty/ sandy/ marine clay/ river sediments
31	yes		yes		yes				pre-Holocene and Holocene deposits
32	yes		yes		yes				
33	yes	yes	yes	yes	yes	yes			
34	yes				yes				
35	yes	yes	yes	yes		yes			
36	yes			yes	yes				
37	yes				yes	yes			
38	yes	yes	yes	yes	yes	yes		highland areas	
39	yes				yes		yes		
40	yes	yes	yes	yes	yes	yes	yes		
41	yes			yes		yes			
42	yes				yes				28 different soil types
43	yes				yes	yes		urban parks	
NEW ZEALAND									
44	yes				yes	yes	yes	yes	
ICP									
45	yes	yes	yes	yes			yes		
46	yes			yes		yes			
47	yes	yes		yes		yes			
NETWORKS									
48	yes	yes	yes	yes	yes	yes	yes	freshwater, upland	
49	yes	yes	yes	yes	yes	yes	yes	yes	
50	yes	yes	yes	yes	yes	yes	yes	yes	
51									
52	yes				yes				

Table 2. Monitoring program descriptions – Part 3

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
NORTH AMERICA								
1	42 sites 126 sample points	landform transect sampling (upper, mid, lower slope) site <0.65 km^2	annual	0-15 cm 15-30 cm	$154,000 (Cdn) establishment cost $25,000 per year (Cdn)	- data used internally for modeling, trend determination and to monitor land use management		14,15,16
2	74 (additional 1 reclaimed site per 100 ha established each yr)	10 m * 40 m plot on upland sites	- reclaimed-5 years - natural-10 years	- principle horizons to 100 cm - composite of 10 subsamples	$5000 (Cdn) per plot to startup	- database used by companies and researchers to guide future reclamation practices		51
3	23 sites 60-100 sample points	25 m * 25 m grid or 5-8 transects per 5-10 ha site (upper, mid, lower slope)	1-10 years	- loose sample of Ap horizon - loose sample of sub-surface horizons	$2.4 million (Cdn) from 1990-1993			140,141,142,143
4	4000	27 km * 27 km grid -4 subplots each 7.32 m in radius	5 years	litter samples 0-10 cm 10-20 cm in mineral soil and forest floor		- stored by a central database - data reported to States annually and complete report every 5 years	-erosion not an issue - pine health decreases with low organic matter - low pH increases birch/beech/maple dieback	12,57,82,99,108, 129,130
EUROPE								
5			- chemical-5 years - physical-10 years			- stored by the Soil Science Institute - used for erosion control and tillage/fertilization systems		85

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
6	514	8.7 km * 8.7 km grid	no scheme	0-30 cm at 10 cm increments and 30-50 cm			-moderate soil acidification, widespread heavy metal pollution, accumulation of nitrogen	10,35,144
7	3		annual	0-5 cm 5-20 cm			-heavy metal concentrations are lower than background standards	49,66
8	303	nation wide						20,49,65
9	240 plots; 200 agr and 40 protected areas	1000 m^2 plot	6 years	-four samples from each genetic horizon			- Cr, Cd Cu, Hg,Pb, Zn contamination	8,19, 27,89,90,145
10	393	country-wide gridnet 50 m^2 plot	10 years	0-25 cm			- heavy metals in arable soils and natural areas don't constitute a serious ecological risk	2,22
11	5692 original samples taken - 904 resampled	5 km * 5 km grid samples taken at 4 m intervals in 400 m^2 plot	15 years	0-15 cm (25 cores per site)		- stored in LandIS database	- decrease in organic carbon and copper, increase in available P, K	35,64,78,96,122,126, 131
12	180 farms/year 900 sampling sites		5 years				- mean pH, P and K in grasslands has decreased - average OM has remained constant	35,96,126
13	3000 permanent plots 7000 temporary plots	country-wide	variable		800,000 Euros/year (field work)	- used in forest management planning, policy decisions and forest inventory planning		26,132
14	150		5 years					25,35

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
15	11 sites 52 sampling points per site	sites approx. 1 ha each in size - country-wide	5 years	- plough layer in agr. soils -pedogenic horizons in forest soils		- data base managed by ORACLE - soil descriptions stored in DONESOL data base		8,11,35,45,59,60
16	102	2 ha plots	10 years	0-10 cm 10-20 cm 20-40 cm	1990-1995 28.5 million Francs	- stored by Coordination Centre for the Technical Research Dept of the National Forest Office		11,45,77,121
17	794	across 16 provinces	periodic				- most important soil changes occur in the organic layers and those changes can be expected within 5-10 years	35,46,91
18	17							35,46
19	276 sample squares, 5 soil samples per square	1 km^2 plots	6-8 years	bulk topsoil sample			- increase in pH -abnormal heavy metal concentrations	4,5,9,35,54,63,123, 124,125
20	865		1-6 years					36,37,138,139
21	183		1-6 years					36,37,138,139
22	189		1-6 years					36,138,139
23	7142 over 5 million ha	12 ha site	3 years	0-30 cm 30-60 cm			- soil acidification had increased 6% and calcareous soils decreased 3%	76,138,139
24	6000 over 5 million ha		3 years	0-30 cm 30-60 cm 60-90 cm				138,139
25	202 points		1-6 years		funded by State Land Service	- stored by State Land Service, reported in annual report	- acidification is increasing	43,118

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
26	75 plots - pesticides and heavy metals 600 - other parameters	400 m^2 fixed plots for heavy metals and pesticides 3-3.5 ha site for other parameters - each site is 200 ha in size	5 years	humic layer 0-20 cm 20-40 cm 40-60 cm	40,000 lita in 2000	- reported annually - detect and track changes in soil indicators, heavy metals and pesticides - assess soil sensitivity to anthropogenic loads and possible impact of contamination on human health	- content of lead is below background levels in most soils - heavy metal accumulations only in humic layer	42,52,61,62,67
27	235	4 km * 4 km plot - distributed 8 km *8 km apart	2-3 years for soil parameters 5 years for heavy metals and pollution	0-5 cm 5-10 cm 10-20 cm 20-40 cm 40-80 cm		- reported annually - identify forest damage, assess background heavy metal concentrations, pathways of accumulation and impact on forests	- least amounts of trace metals found in podzolic and marshy soils - most soils are not heavily contaminated with trace metals	42,52,67,135,136
28	1	13.65 km^2 watershed	2-5 years		5000 lita in 2000	- data reported once per year by the Lithuanian Water Management Institute		42,52,67,94
29	100 (35- 40 yearly)	400 m^2 site	annual	0-10 cm 30-50 cm		- stored by RIVM	- accumulation of heavy metals in arable and cattle farms	30,31,32,33,35,73, 74,137
30	1683 samples	based on size of homogenous area 10,000 m^2 site	10-15 years	topsoil			- agricultural areas have higher concentrations of zinc and copper and have higher pH levels	13,35,73,74,137
31			5 years			- stored by RIVM		74,137

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
32		15 catchments <10 km^2 site					- processes are primarily driven by weather events leading to largely variable seasonal and annual nutrient loss rates	22,80,133,134
33	227 (45,000 samples)	100 m^2 plot	5 years 10 years in forests	0-20 cm or 0-10 cm in (grasslands)			- natural content of heavy metals and sulphate	107,109,116,117
34	151 samples	218 000 km^2		0-20 cm			- PAH levels low	55,107
35	1461	1 plot per 60 km^2	4 years			- published in full in Environmental Monitoring Library	- decreasing concentrations of SO_2 and NO_2 in air pollutants	17,18
36	20-22 areas		4-5 years		6,788,000 Estonian crowns in 1994	- data is stored in a meta-database	- lowest biodiversity on lands abandoned less than 4 years ago	81,87,88,92,93
37	942; 670 agr. and 272 forested	16 km^2 grid 400 m^2 plot at each node point	4 years					23,72,86,120
38	650; 312 agr. and 338 forested	314 m^2 site	5 years	0-10 cm 20-30 cm 35-45 cm 10-30 cm in agric soils		- stored in Information System of Monitoring - results reported in State of the Environment Report	- 98.6% of soils are not contaminated - trace elements are not high	47,48,68,69,70,71, 97,98,100
39	300		5 years				- highest organic matter found in mountain soils such as rendzina and podzols	3,47

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
40	4 sites 1 or 2 plots per watershed	50 m * 50 m plot / watershed 1 km^2 watershed	2-10 years	0-5 cm 5-10 cm 10-20 cm 20-30 cm 30-60 cm	109 million SEK for entire program	- data hosts have been established to store and distribute quality assured environmental data	- soils predominantly podzols	7,111,114
41	23,500	circular plots (7-10 m radius)	10 years	- samples taken up to 1m deep	10 814 thousand SEK in 2001	-data stored in the SK-BAS database - annual publication		8,110,111,112,113
42	40 sites	2-15 km^2 site		0-20 cm 40-60 cm	6580 thousand SEK in 2001			110,111
43	107; 74 agr., 31 forested and 2 urban p arks	100 m^2	5 years	0-20 cm, 4 composite samples from 25 sample locations in a square grid pattern		- data is included in the NABO- database	- after five years, 87 of 100 sites showed a change in one measured pollutant - the main inorganic pollutants are a consequence of anthropogenic contamination	115
NEW ZEALAND								
44	511	10 regions 40 m transect with five 25 m^2 plots at 1 m spacings 20 cores per plot	anticipated to be 5-10 years	0-10 cm 0-7.5 cm for BD and macro porosity		- data used for State of Environment reporting	- soil quality is within acceptable levels - structural degradation on half of arable cropping and market garden sites	56,79,101,102,103, 104,105,106

Prog. No.	No. of Sampling Points	Spatial Variability Sampling Pts	Sampling Interval of Soil	Sampling Method	Project Costs	Data	Data Trends	References
ICP								
45	70 sites	40 m * 40 m plot 10-1000 ha sites	5 years	0-5 cm 5-10 cm 10-20 cm 20-40 cm 40-80 cm		- data submitted to National Focal Point and then to Programme Centre		8,40,83,127
46	6000 (5300 soil)	16 km * 16 km grid	10 years	0-10 cm 10-20 cm				8,38,39,84,128
47	860	0.25 ha plot surrounded by 10 m buffer zone	10 years	0-10 cm 10-20 cm 20-40 cm 40-80 cm		- stored at the Forest Intensive Monitoring Coordinating Institute	- depositions of nitrogen, acidity and heavy metals exceed critical loads over a large portion of plots	8,38,39,84,128
NETWORKS								
48	12 terrestrial sites 37 freshwater sites	9 ha site - soil sampled on 1 ha on 50 m and 25 m grids	5 years / 20 years	0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm and by horizons for first 30 cm	50,000 British pounds/year/site			6,8,24,34,119,126
49	1700 sites	120 countries						28
50		25 countries						41
51								50,95
52		16 km * 16 km grid	possibly 5, 10 -20 years					35,75

Table 3. Soil, site and management parameters measured by monitoring programs[1]

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
NORTH AMERICA										
1	N, P, K, S, NH_4	pH, EC, $CaCO_3$, TOC, Total N, CEC (at site establishment)	Db, PSA (at site establishment), soil water characteristics in 2003	hot KCl-NH_4	LFC, LFN	B, Cl, Co, Cu, Fe, Mg, Mn, Mo, Ni, Se, Si, V, Zn (once in 2003)	2,4-D sorption (once) Ag, Al, As, Ba, Be, Bi, Cd, Cr, Li, Pb, Sb, Sn, Sr, Ti, Tl (once in 2003)	yes	yes	yes
2	N, P, K, S, Ca, Mg	pH, EC, CEC, $CaCO_3$	Db, PSA			trace metals	trace metals, hydrocarbons		yes	
3	P, K	pH, EC, CEC, $CaCO_3$, TOC, Total N, Total K, Total Na, Total Mg, Total Ca	Db, hydraulic conductivity, soil moisture, PSA, aggregate stability, ^{137}Cs	mesofauna		Co, Cu, Fe, Ni, Zn	Al, Cr, Li, Pb	yes	yes	yes
4	P, S	pH, CEC, Total inorganic C, Total C, TOC, Total N, $CaCO_3$	Db, soil moisture, PSA, aggregate stability, penetration resistance			Mn, Ni, Cu, Zn	Ba, Cd, Pb, Sr		yes	
EUROPE										
5		pH, hydrolytic acidity, CEC, $CaCO_3$, Total N, Total P, P fractions, soil greenhouse analysis, sorptive capacity	Db, porosity, soil water characteristics, PSA, aggregate stability	Nmin	organic humus, humus fractions	Cu, Fe, Mn, Zn	Ba			
6	yes	pH, CEC, $CaCO_3$, TOC, Total N	PSA				As, Cd, Pb		yes	
7		pH, EC				Co, Cu, Ni, Zn	Cd, Pb			yes
8	SO_4					Cu, Zn	As, Cd, Pb			

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
9	P, K, Ca, Mg	pH, exchangeable acidity, CEC, TOC, Total P, Total K, Total Ca, Total Mg	Db, specific gravity, porosity, FC, PSA	Nmin, micro-biological, enzyme activity, mesofauna		B, Co, Cu, Fe, Mn, Mo, Ni, V, Zn	As, Be, Cd, Cr, Hg, Pb, Tl, pesticides, PCB, radionuclides	yes		
10						Cu, Ni, Zn	As, Cd, Cr, Hg, Pb			
11	P, K, Mg	pH, TOC, Total Na, Total Ca, Total P, Total K,	PSA, soil water characteristics			Co, Cu, Fe, Mg, Mn, Mo, Ni, Se, V, Zn	Al, Ar, Ba, Cd, Cr, F, Hg, Pb, Sr	yes	yes	
12	P, K, Mg	pH, TOC						yes		
13										
14	yes					yes	yes			
15	PO_4, Ca, Mg, K	pH, TOC, Total N, CEC, $CaCO_3$	PSA, Db	Nmin, Cmin, mesofauna, micro-biological, enzyme activity	LFC, LFN	Co, Cu, Ni, Zn	Cd, Cr, Pb radionuclides	yes	yes	
16	yes	TOC, Total N						yes	yes	yes
17	Ca, K, Mg, Na	pH		yes	humus	Zn	Al, Cd, Pb, Sb, Tl	yes		
18							heavy metals, hydrocarbons			
19		pH, TOC		micro-biological, macrofauna, enzyme activity		Cu, Ni, V, Zn	Cd, Pb, PCB, hydrocarbons, pesticides		yes	

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
20	N, P, K, S, Ca, Mg, NO_2	pH, EC, CEC, TOC, Total N, $CaCO_3$	hydraulic conductivity, soil water characteristics, PSA	micro-biological, respiration	humus content	B, Cl, Cu, Co, Fe, Mn, Mo, Ni, Se, Zn	Al, As, Cd, Cr, Hg, Pb, organic micropollutants, pesticides, radionuclides		yes	
21	N, P, K, S, Ca, Mg, NO_2	pH, EC, CEC, TOC, Total N, $CaCO_3$	hydraulic conductivity, soil water characteristics, PSA	micro-biological, respiration	humus content	B, Cl, Cu, Co, Fe, Mn, Mo, Ni, Se, Zn	Al, As, Cd, Cr, Hg, Pb, organic micropollutants, pesticides, radionuclides		yes	
22	N, P, K, S, Ca, Mg, NO_2	pH, EC, CEC, TOC, Total N, $CaCO_3$	hydraulic conductivity, soil water characteristics, PSA	micro-biological, respiration	humus content	B, Cl, Cu, Co, Fe, Mn, Mo, Ni, Se, Zn	Al, As, Cd, Cr, Hg, Pb, organic micropollutants, pesticides, radionuclides		yes	
23	N, P, K, S, Ca, Mg	pH, EC, $CaCO_3$, TOC, Total N	soil water characteristic			Cu, Mn, Zn		yes	yes	yes
24		Total P, Total K, Total S, Total Na, Total Mg, Total Ca				B, Co, Cu, Fe, Mn, Mo, Ni, Se, Zn	Al, Cd, Cr, Hg, Pb			
25	N, P, K	pH, TOC	Db, porosity, WP, WHC	mesofauna		Cu, Ni, Mn, Zn	Cd, Cr, Pb, pesticides, radionuclides	yes		
26	P, K, Ca, Mg	pH, EC, TOC, Total S			organic humus, sulfur content of humus fractions	Cu, Fe, Ni, Zn	Cd, Cr, Pb, pesticides			

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
27	Na, S	pH, CEC, exchangeable acidity, TOC, $CaCO_3$, Total C, Total N, Total P, Total K, Total Mg, Total Ca			humus fractions	Cu, Fe, Ni, Mn, Zn	Al, Cd, Cr, Pb			
28	NH_4, NO_3, SO_4, K, Ca, Mg, Na	pH, EC, CEC, TOC, Total N, Total C, Total P, exchangeable acidity, Total S, sorptive capacity	Db, PSA	Nmin, enzyme activity	litter/cellulose decomposition	Cl, Cu, Fe, Mn, Ni, Zn	Al, Cd, Cr, Pb, pesticides, radionuclides	yes	yes	
29	PO_4, NH_4, NO_3, SO_4	pH, EC, TOC, Total K				Cu, Cl, Mg, Zn	Cd, Pb, PAH, hydrocarbons, pesticides			
30	NH_4, NO_3, PO_4, K, Ca	pH, TOC	PSA			Cu, Fe, Ni, Zn	Al, Cr, Pb, PAH, hydrocarbons			
31	NO_3, P						Cd, pesticides			
32	yes	yes	yes			yes	pesticides	yes	yes	
33	PO_4, K, S, Ca, Mg, Na	pH, CEC, $CaCO_3$, Total C, Total N, TOC, sorptive capacity	Db, PSA		humus fractions	B, Cu, Mn, Ni, Se, V, Zn	Al, As, Be, Cd, Cr, F, Hg, Pb	yes	yes	
34		pH, TOC	PSA				PAH			
35	P, K, SO_4, Ca, Mg, Na, NH_3, NH_4, NO_3					Cl, Cu, Fe, Mn, Zn	Al, Cd, Pb			
36	P, K	TOC, Total N	soil moisture	mesofauna, micro-biological						
37		yes	yes				organochlorine pesticides		yes	

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
38	P, K, Mg, Ca	pH, EC, CEC, TOC, Total N, Total P, Total K, Total Mg, Total C, KCl	Db, porosity, infiltration rate, PSA		organic humus, humus fractions, oxidizable C	Co, Cu, Ni, Se, Zn	Al, As, Cd, Cr, F, Hg, Pb, organic pollutants, radionuclides, halogenated compounds, PAH			
39		TOC, Total N			humus fractions					
40	PO_4, K, Ca, Mg, Na, NH_4, NO_3	pH, CEC, Total C, Total N, Total P, Total S, exchangeable acidity				Cl, Cu, Fe, Mn, Zn	Al, Cd, Hg, Pb			
41		pH, CEC, Total C, Total N	PSA		litter/cellulose decomposition	yes	yes	yes	yes	
42	yes	yes			humus	yes	heavy metals, organochlorine pesticides			
43	P, Ca	pH, CEC, aluminum oxide	Db, PSA		humus fractions	Co, Cu, Fe, Ni, Zn	Cd, Cr, F, Hg, Pb, halogenated compounds, PAH			
NEW ZEALAND										
44	P	pH, CEC, Total C, Total N	Db, porosity, soil water characteristics, PSA, aggregate stability	Nmin, respiration, microbial biomass		Fe			yes	

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
ICP										
45	K, Ca, Mg, Na	pH, CEC, TOC, Total N, Total P, Total S	Db, PSA	Nmin, enzyme activity, respiration	litter/cellulose decomposition	Cu, Fe, Mn, Mo, Ni, Zn	Al, As, Cd, Cr, Hg, Pb			
46	Na	pH, CEC, $CaCO_3$, TOC, Total N, Total P, Total K, Total Mg, Total Ca				Cu, Fe, Mn, Ni,, Zn	Al, Cd, Cr, Pb		yes	
47	P, K, S, Ca, Mg, Na	pH, EC, CEC, TOC, $CaCO_3$, Total N, Total K, Total Na, Total Ca, Total Mg				Cu, Fe, Mn, Ni, Zn	Al, Cd, Cr, Hg, Pb		yes	
NETWORKS										
48	N, P, NH_4-N, S	pH, CEC, exchangeable acidity, $CaCO_3$, TOC, Total inorganic carbon, Total N, Total P, Total S	Db, PSA, soil water characteristics	micro-biological		Co, Cu, Fe, Mo, Ni, Zn	Al, As, Cd, Cr, Hg, Pb	yes	yes	yes
49	P	pH, CEC, TOC, $CaCO_3$, Total, N, Total C, Total P, exchangeable acidity	Db, PSA, infiltration, soil water characteristics	macrofauna, microfauna, microflora, respiration		B, Cl, Co, Cu, Fe, Mn, Mo, Ni, Zn	Cd, Cr, Hg, Pb		yes	
50										
51										

Prog No.	Soil Test Analysis (Fertility)	Soil Chemical Properties	Soil Physical Properties	Soil Biological	Soil Biochemical	Micro-nutrients	Pollutants	Mgt	Site Description	Climate Data
52	N, P, K, S, Mg	pH, EC, CEC, Total C, Total N, Total P	Db, hydraulic conductivity, infiltration rate, PSA, soil water characteristics, aggregate stability, shrinkage/ swelling tests, plastic/liquid limit	Nmin, Cmin, micro-biological, enzyme activity, respiration	humus fractions, particulate organic matter	Cu, Mo, Mn, Ni, Se, V, Zn	Al, As, Cd, Cr, F, Hg, Pb, pesticides, radionuclides, surfactants, halogenated compounds, PAH, PCB	yes	yes	

[1]**<u>NOTES:</u>**
SOIL TEST ANALYSIS (fertility): can include measurements of N, P, K, S, Ca, Mg, Na, NH_4, NH_3, NO_2, NO_3, PO_4, SO_4
SOIL CHEMICAL: can include TOC, Total inorganic carbon, soil greenhouse analysis, sorptive capacity, pH, EC, $CaCO_3$, CEC, base saturation, acid and base cations, soluble cations, exchangeable cations, exchangeable acidity, hydrolytic acidity, sodicity, Total N, Total P, Total K, Total S, Total Mg, Total Ca, Total Na, SAR
SOIL PHYSICAL: can include Db, compaction, penetration resistance, total porosity, macroporosity, infiltration rate, shrinkage/swelling tests, plastic/liquid limits, saturated and near-saturated hydraulic conductivity, aggregate stability, texture, PSA, specific gravity and soil water characteristics
SOIL BIOLOGICAL: can include Nmin, Cmin, respiration, microbiology, microfauna, mesofauna, macrofauna, microflora, microbial biomass activity, enzyme activity and earthworms
SOIL BIOCHEMICAL: can include measurements of LFC, LFN, organic humus, humus fractions, litter/cellulose decomposition, oxidizable C, particulate organic matter
MICRONUTRIENTS: can include measurements such as B, Cl, Co, Cu, Fe, Mg, Mn, Mo, Ni, Se, Si, V, Zn
POLLUTANTS: can include measurements of Ag, Al, As, Ba, Be, Bi, Cd, Cr, F, Hg, Li, Pb, Sb, Sn, Sr, Ti, Tl, PCBs, PAH, halogenated compounds, surfactants, tricyclic aromatic hydrocarbons, organochlorine pesticides, herbicide residues, chlororganic insecticides, radionuclides
MANAGEMENT: can include land use history, site history, crop residues, cultivation, vegetation composition, plant yield, plant quality, manure application, manure storage, fertilization
SITE DESCRIPTION: can include morphology, soil profile description, soil type, soil series, soil classification, mass of forest litter, type/depth of humus horizon, landscape attributes, slope, aspect, relief, soil parent material, erosion/deposition, weathering, mineralogy/rock type, hydrological conditions, phases/stages of soil development

Soil Water Characteristics: can include water holding capacity, field water capacity, total available water, readily available water, soil moisture, hygroscopic moisture content, soil water release, soil moisture retention, wilting point, saturation point
FC: field capacity; the content of water, on a mass or volume basis, remaining in a soil 2 or 3 days after having been wetted with water and after free drainage is negligible
WP: wilting point; the percentage by weight of water remaining in the soil when the plant wilts permanently
WHC: water holding capacity
pH: the degree of acidity or alkalinity of a soil, expressed as a measure of free hydrogen ion activity in the soil on a scale from 1-14
EC: electrical conductivity or a measure of soluble salt content of soil
CEC: cation exchange capacity; the total amount of exchangeable cations that a soil can adsorb. It is sometimes called "total exchange capacity", "base exchange capacity" or "cation adsorption capacity"
TOC: total organic carbon, includes measures of organic matter
Db: bulk density; the mass of dry soil per unit bulk volume; includes measures of compaction and resistance
PSA: particle size analysis; determination of the various amounts of the different soil separates in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods
LFC: light fraction carbon, amount of carbon in the proportion of soil which is less than 2.0 g cm^{-3}
LFN: light fraction nitrogen, amount of nitrogen in the proportion of soil which is less than 2.0 g cm^{-3}
Nmin: mineralizable nitrogen
Cmin: mineralizable carbon
PCB: polychlorinated biphenyls
PAH: polycyclic aromatic hydrocarbons

4.1 Countries/Organizations
The 52 monitoring programs reviewed are distributed across the world with the majority (80%) being situated in Europe (Figure 2). Thirty-nine programs originate in 21 different European countries. Since 80% of the programs originate in Europe, it appears that soil monitoring may be more of a priority in Europe than in other areas of the world or perhaps information regarding environmental monitoring in Europe may be more accessible to the public. Sixteen of the 21 European countries are also member states of the European Union and perhaps environmental monitoring is mandatory as part of membership. Arrouays et al (1998) noted that European soil monitoring networks result primarily because of soil acidification and the effects of air pollution. These issues seem to be addressed more in the northern and eastern European countries than over the rest of the continent. Three United Nations programs and five international/European networks were also found. Networks provide a setting for the collection and sharing of information.

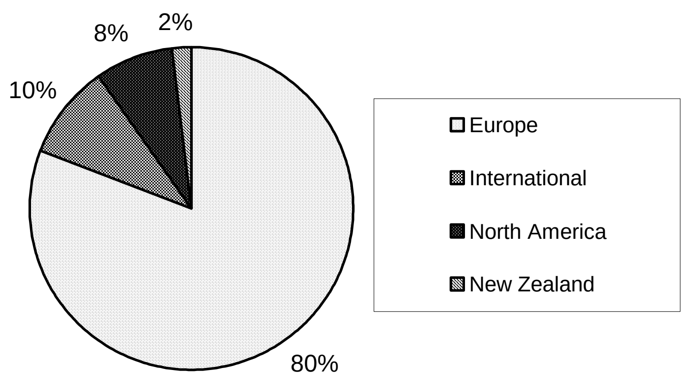

Figure 2. Distribution of monitoring programs by location

4.2 Management
A majority of monitoring programs are conducted at the national level and are managed by governmental organizations. For example, nine programs are managed by Departments of Agriculture, four by Departments of Forestry and 12 by Departments of Environment. Government controlled institutes and universities manage 11 programs, while eight are managed by non-governmental organizations and private industry. The remaining eight programs are managed at the provincial level or the managing party was not stated in the literature. The AESA Soil Quality Benchmark Program is operated at the provincial level within the Alberta Department of Agriculture, Food and Rural Development.

4.3 Objectives/Purpose
The range of program purposes or objectives includes determining the state/trends in soil, forests or ecosystems due to human involvement, developing approaches to address the issues, data storage and exchange of information, to solely identifying risks to the food chain and researching the cause and effect of forest dieback. Monitoring schemes differ in their primary objectives

because of differences in environmental concerns. Although not stated as the key objective, the strongest single reason for soil monitoring may ultimately be the crucial role the soil plays in food production and the potential risk of contamination of the food chain (90). The objective of the AESA Soil Quality Benchmark Program is to determine the effect of different management practices on soil quality and to collect data for validation of modeling exercises. Twenty-seven programs have the purpose of determining the status and trends of soil, which is similar to the AESA Soil Quality Benchmark Program. Eighteen programs, including the AESA program, make reference to using the data they collect for modeling purposes.

4.4 Establishment Period

Program establishment has spanned several decades ranging from the 1920's to plans for the future (Figure 3). The earliest monitoring program began in Finland in 1921, while two monitoring systems in Table 2, the Networking of Long-term Integrated Monitoring of Terrestrial Systems (program number 51) and the European Soil Monitoring Network (program number 52), will become operational in Europe in the future. The literature indicates that only five programs have officially been terminated. The majority of the programs were initiated in the late 1980's and early 1990's. This probably corresponds to increasing environmental consciousness and concern about issues regarding land use sustainability. The late appearance of soil monitoring systems and perhaps the complete absence of soil monitoring in many environmental monitoring programs may be due to the lack of awareness of the functions soil performs or its slow reaction to contamination (74), which makes it easy to ignore. The AESA Soil Quality Benchmark Program has monitored soil quality annually for the last five years and is planning to continue for at least five to ten more years.

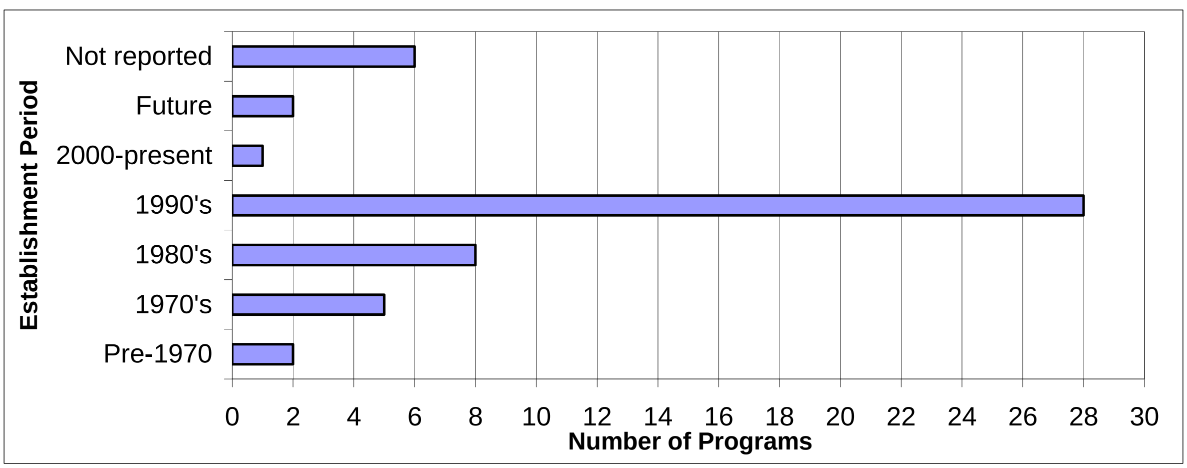

Figure 3. Distribution of monitoring program establishment period

4.5 Components Monitored

The programs were grouped according to the ecosystem components that each measures (Figure 4). Twelve programs follow an integrated approach by measuring a combination of four ecosystem components (soil, biota, air and water). Eleven programs measure only soil and biota (plant and/or animal), similar to the AESA Soil Quality Benchmark Program. Seventeen of the 52 programs have soil as the only focus of their monitoring efforts.

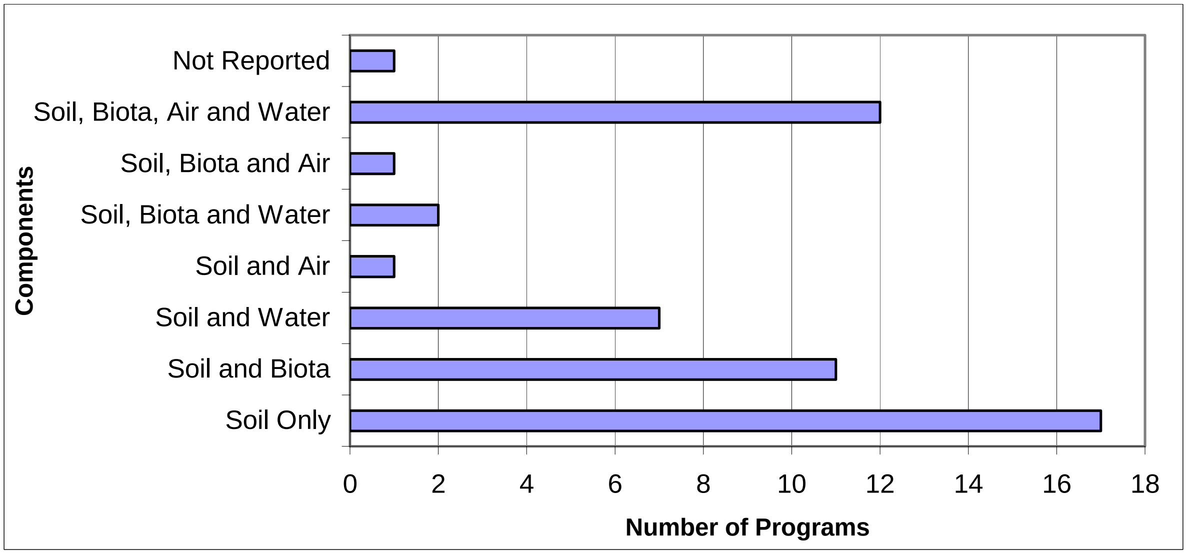

Figure 4. Distribution of monitoring programs by ecosystem components measured

4.6 Ecosystems Monitored

The programs were grouped according to the type(s) of ecosystems that they monitored (Figure 5). Land used by agriculture is the focal point of most of the monitoring programs as seventeen solely monitor variables on agricultural land. The AESA Soil Quality Benchmark Program only measures parameters in the agricultural ecosystems of Alberta. Ten of 52 programs focus on forested ecosystems, while two programs incorporate the monitoring of agricultural, forested, and natural areas and six others programs monitor agricultural, forested, natural and other ecosystems. Referring to sections 4.5 and 4.6, only four monitoring programs are similar to the AESA Soil Quality Benchmark Program and exclusively measure soil and biota on agricultural land. These programs are 3, 23, 25, and 36 (Table 2).

4.7 Soil Sampling Interval

Distribution of the sampling interval for the soil component is reported (Figure 6). Sampling intervals range from one to 20 years depending on the parameter measured. Within a program, an interval such as “1-6” means that some soil attributes are measured annually while others are measured every six years. A five-year interval is the most commonly used sampling scheme. The AESA Soil Quality Benchmark Program measures most soil attributes on an annual basis, which may be too frequent as changes in soil status may be difficult to determine using sampling intervals less than five years (126).

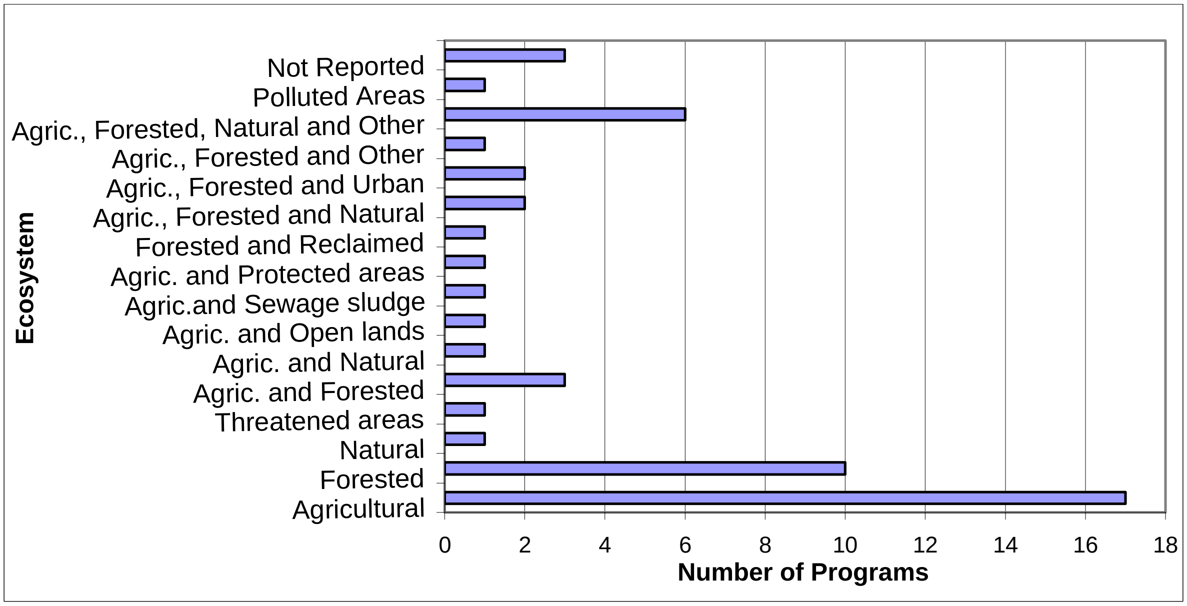

Figure 5. Distribution of ecosystem type(s) monitored

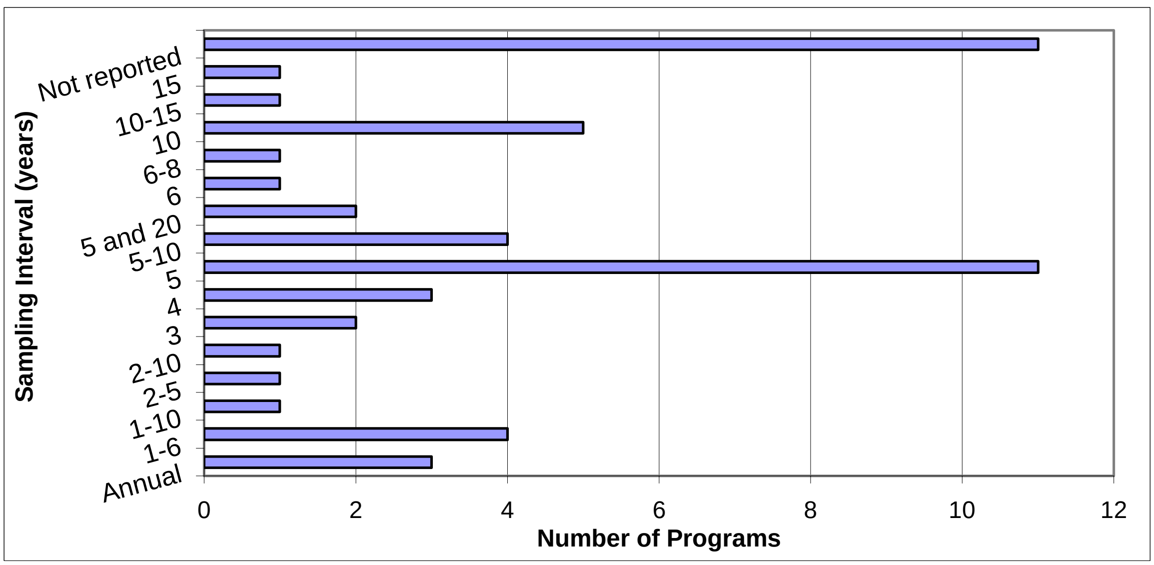

Figure 6. Distribution of interval (in years) between soil sampling events

4.8 Sampling Spatial Variability

Monitoring programs use various approaches to sampling (Table 2). Spatial variability across a landscape can occur due to differences in natural soil forming factors, topsoil depth, fertility, landform and management. The AESA Soil Quality Benchmark Program and the Canadian Soil Quality Benchmark Site Program (program number 3) stratify their sample points by ecodistrict and topography. Both programs measure soil properties at various slope positions along a catena and chose sample sites based on areas of relatively homogeneous biophysical and climatic conditions. Landform based measurement ensures that variability caused by differences in moisture, temperature, vegetation and other soil factors are captured during sampling. A grid-sampling scheme, which covers an entire site or region at regular intervals is used by programs 3, 4, 6, 10, 11, 27, 35, 37, 46 and 52. Grid based sampling is the easiest way to ensure coverage of large areas and enables unbiased estimates. Others chose specific sampling points based in a watershed/catchment area or simply areas representative of land use, management or soil type within a region or across the entire country.

4.9 Parameters

The parameters measured by each program are reflective of its given objectives or purpose. Each program could measure a total of ten selected soil, site and management parameters. The parameter classes selected for analysis in Table 3 are:

- soil test analysis
- chemical
- physical
- biological
- biochemical
- micronutrients
- pollutants
- management information
- site description
- climatic data

The ability of a soil to function is determined by interactions between various physical, chemical and biological soil attributes. These parameters make up a minimum dataset of parameters needed to monitor overall changes in soil quality.

Programs were grouped according to the number of the parameters mentioned above that each measures. A majority measure fewer than six parameters, five measure nine of ten parameters, while five programs including the AESA Soil Quality Benchmark Program, regularly measure eight of ten parameters (Figure 7). Each parameter is discussed below in more detail.

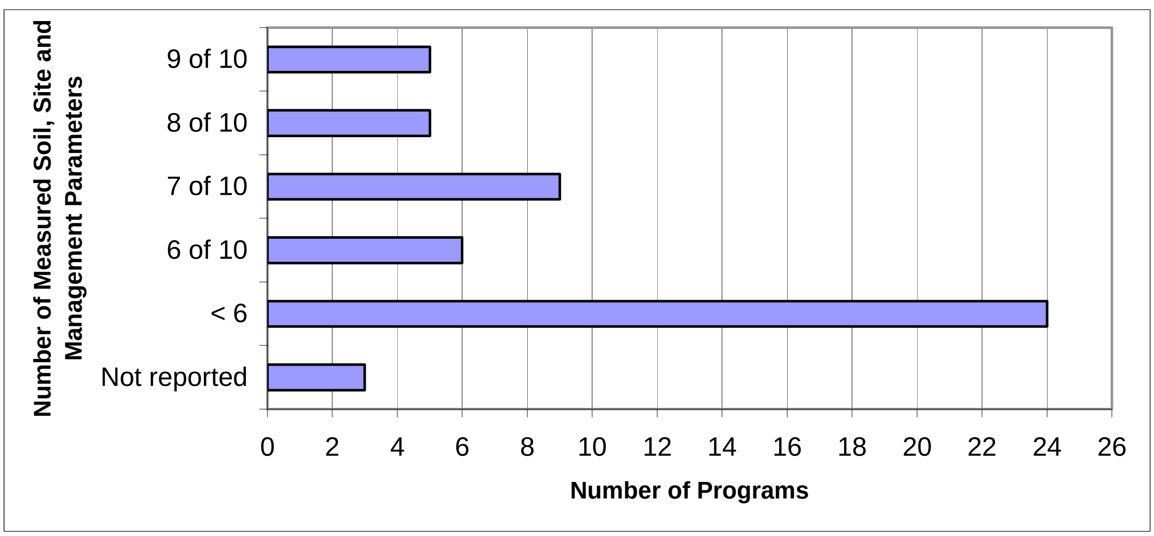

Figure 7. Distribution of the number of soil, site and management parameters measured

4.9.1 Fertility

Selected soil attributes which contribute to the fertility of a soil are measured by 39 of 52 programs (Table 3). Soil test analysis are used to indicate nutrient availability in a soil, which helps explain plant growth and yield patterns. The measurement of fertility can include N, P, K, S, Ca, Mg, Na, NH_4, NH_3, NO_3, PO_4, and SO_4 The AESA Soil Quality Benchmark Program uses soil test analysis for calculation of nutrient balances and for modeling exercises.

4.9.2 Chemical

Chemical soil attributes are measured by 43 of 52 programs (Table 3). Many chemical measurements are dynamic and change under human induced pressures. Their measurement is necessary to understand soil function and the effects of use and management on the soil resource.

4.9.3 Physical

Physical attributes are also essential to understand how well soils are functioning. Twenty-nine programs include the monitoring of physical soil attributes in their protocols (Table 3). The AESA Soil Quality Monitoring Program uses measurements of bulk density, particle size and moisture as indicators of physical soil parameters. Five of 52 programs include the measurement of aggregate stability.

4.9.4 Biological

The inclusion of biological attributes in soil quality assessment is continually evolving and many attributes are being evaluated for use as soil quality indicators. Soil biological attributes are measured by 18 programs (Table 3). Of those 18 programs, seven measure nitrogen mineralization. Currently, the only biological indicator measured by the AESA Soil Quality Benchmark Program is potentially mineralizable nitrogen. Other programs also include mineralizable carbon, mesofauna, microfauna and soil enzyme activity as biological measurements.

4.9.5 Biochemical

Eighteen programs measure soil biochemical attributes (Table 3.) Measurements include humus, light fraction organic matter and decomposition. The AESA program measures light fraction (LF) organic matter and light fraction carbon (LFC) and nitrogen (LFN). Light fraction organic matter is enriched with carbon and nitrogen and is an indicator of changes in the biologically active portion of organic matter.

4.9.6 Micronutrients

Monitoring for micronutrients occurs in 40 of 52 programs (Table 3). Micronutrients necessary for plant growth include boron, chlorine, cobalt, copper, iron, magnesium, molybdenum, nickel, selenium, silicon, vanadium and zinc. In 2002, the AESA Soil Quality Benchmark Program looked at micronutrient content in agricultural soils across Alberta for the first time. Annual analysis does not currently occur but a future need may arise as industry and food production systems further impact the environment.

4.9.7 Pollutants

Pollutants are measured in 43 of 52 programs (Table 3). The pollutant category can include measurements of heavy metals, pesticides, radionuclides and hydrocarbons. Heavy metals may include silver, aluminum, arsenic, barium, beryllium, bismuth, cadmium, chromium, lithium, lead, antimony, tin, strontium, titanium, thallium, fluorine, and mercury. These elements can become pollutants if their concentrations reach levels high enough to cause contamination. Pollutant monitoring is primarily concentrated in Europe which may be due to high population densities and a history of intense industrialization throughout the continent . Pollutant buildup in the environment has large economic consequences and heavy metal buildup may be irreversible in a human lifetime (119). The AESA Soil Quality Benchmark Program performed a one time analysis of heavy metals in 2002 and also collaborated with the University of Manitoba to measure 2, 4-D sorption values (ratio of 2, 4-D sorbed to the soil relative to the amount in solution) in agricultural soils of Alberta. Other pesticides have not been monitored or determined and further heavy metal monitoring is not currently planned.

4.9.8 Management

Land management information such as crop rotation, crop yield, tillage and fertilization is collected by 16 programs (Table 3). This information is important to explain productivity, nutrient cycling and changes in soil properties. The AESA Soil Quality Benchmark Program collects this type of information on an annual basis by interviewing the land managers and harvesting plant samples from each site.

4.9.9 Site Description

Site descriptions and soil characterization such as landscape and soil type are useful to interpret soil analysis data as they help explain changes in soil quality and are important inputs of any modeling program. This information is collected by 24 programs (Table 3). The AESA Soil Quality Benchmark Program collected site information and characterized the soil when the sampling sites were initially selected.

4.9.10 Climatic Data

Climatic data is documented by six of the 52 programs (Table 3). Climatic data is important to interpret soil data because temperature and moisture have a large influence on numerous soil processes such as microbial activity, mineralization, and various physical characteristics. Climate also drives many soil models. The AESA Soil Quality Benchmark Program collects precipitation on site with manual rain gauges and uses climatic data collected at Environment Canada weather stations across Alberta to interpret soil data from the benchmark sites.

4.10 Trends

After monitoring has been conducted for a period of time, trends in changes of soil properties can be determined. Many programs produce reports which include the state of the soil resource at one point in time and do not describe changes in soil properties between monitoring periods.

4.11 Comparison of Parameters Measured

The parameters measured by the AESA Soil Quality Benchmark Program and those that are not included in the sampling protocol but are measured by other programs are given in Table 4. A blank cell indicates that the AESA program is currently measuring all parameters being measured by others in the particular category.

Table 4. Comparison of parameters measured by AESA Soil Quality Benchmark Program to other monitoring programs

Parameters Measured By AESA Soil Quality Benchmark Program	Parameters Measured By Other Programs Not Included in the AESA Soil Quality Benchmark Program
Soil Test Analysis (Fertility)	
NO_3, PO_4, K, SO_4, NH_4	Ca, Mg, Na, NO_2, NH_3
Soil Chemical	
pH, EC, $CaCO_3$, TOC, Total N, SAR if EC>4, CEC (at site establishment)	Total P, Total K, Total S, Total Na, Total Mg, Total Ca, Total C, Total inorganic C, K fractions, P fractions, soil greenhouse analysis, sorptive capacity, hydrolytic acidity, exchangeable acidity, base saturation, acid/base cations, soluble cations, exchangeable cations, sodicity
Soil Physical	
Db, PSA (at site establishment), wilting point (once), field capacity (once)	aggregate stability, total porosity, macroporosity, compaction, penetration resistance, saturated hydraulic conductivity, near-saturated hydraulic conductivity, specific gravity, water holding capacity, total available water, hygroscopic moisture, soil water release, saturation point, infiltration rate, shrinkage/swelling tests, plastic/liquid limit
Soil Biological	
Nmin potential	Nmin, Cmin, mesofauna, macrofauna, microfauna, microflora, respiration, microbiology, enzyme activity, microbial biomass activity, earthworm concentrations
Soil Biochemical	
LFC, LFN	organic humus, humus fractions, particulate organic matter, litter/cellulose decomposition, oxidizable C
Pollutants	
pesticide (2,4-D) sorption values (once), Ag, Al, As, Ba, Be, Bi, Cd, Cr, Li, Pb, Sb, Sn, Sr, Ti, Tl (all sampled once)	organochlorine pesticides, hydrocarbons, radionuclides, PCB, halogenated compounds, PAH, surfactants, F, Hg
Micronutrients	
B, Cl, Co, Cu, Fe, Mg, Mn, Mo, Ni, Se, Si, V, Zn (all sampled once)	
Management	
land use history, plant yield, plant quality, manure applications, fertilizer applications, pesticides/herbicides, cultivation activity, crop type, cropping rotations	
Site Description	
legal land descriptions, air photos, profile descriptions, soil classification, site characterization, topsoil depth, parent material, horizon descriptions, slope position, aspect, erosion, moisture regime, drainage, stoniness	
Climate Data	
annual precipitation	