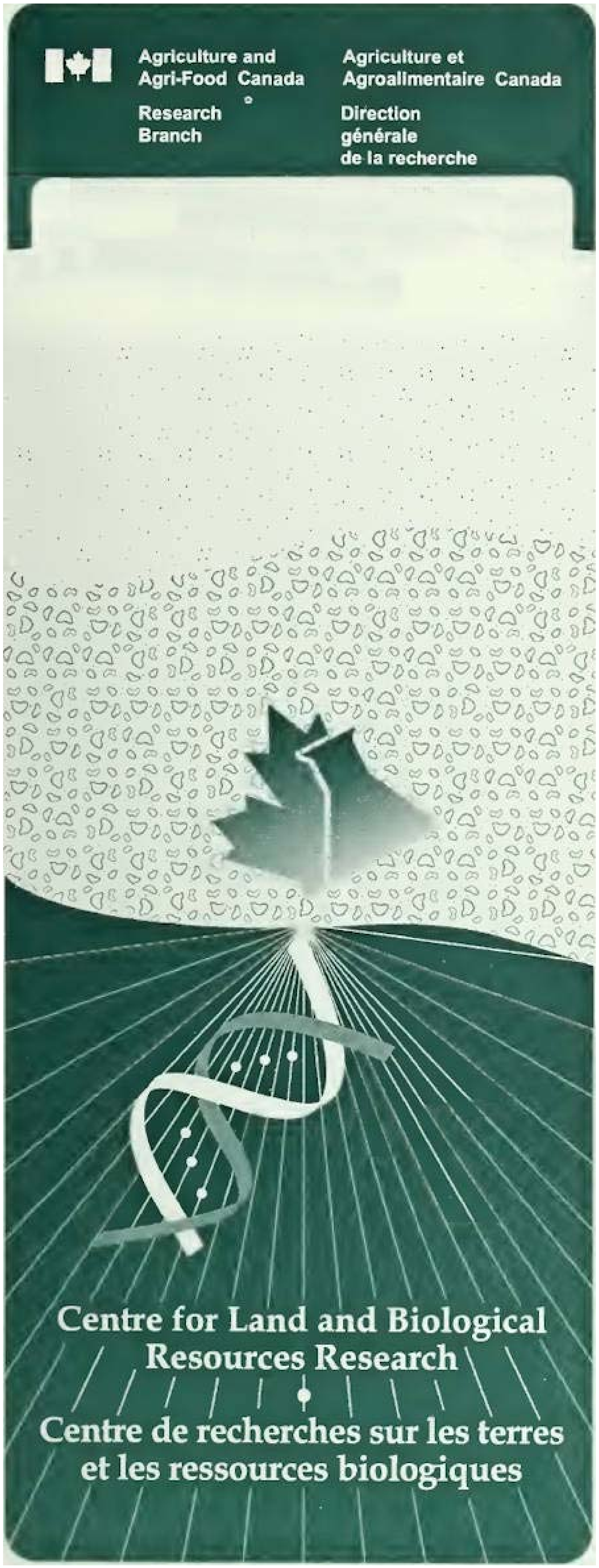

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A Program to Assess the Impacts and Benefits of Composted Source-Separated Solid Wastes (CSSSW) Applied to Agricultural Lands: National Agricultural Compost Trial

Canada

A Program to Assess the Impacts and Benefits of Composted Source-Separated Solid Wastes (CSSSW) Applied to Agricultural Lands: National Agricultural Compost Trial

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A program to assess the impacts and benefits of Composted Source-Separated Solid Wastes (CSSSW) applied to agricultural lands

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EXECUTIVE SUMMARY

The Solid Waste Management Division of the Hazardous Waste Management Branch of Environment Canada contracted the Centre for Land and Biological Resources Research (CLBRR) of Agriculture and Agri-Food Canada (AAFC) to prepare a report on the design of a National Agricultural Compost Trial (NACT). The NACT was to focus on assessing the soil and environmental benefits and risks associated with the application of Composted Source-Separated Solid Wastes (CSSSW) to agricultural land. CLBRR's interest was enhanced by Canadian Council of Ministers of the Environment (CCME) programs requiring a 50% reduction in waste to landfill by the year 2000, and the perceived likelihood of increasing pressure on agricultural lands to accept composted organic residues.

This report provides a perspective on issues and presents concepts for the design of a NACT. It includes three main parts: A) results from a workshop on CSSSW application to agricultural lands; B) review of issues related to CSSSW application; and C) recommendations for the implementation and coordination of the National Agricultural Compost Trial. Various appendices indicate the participants of the workshop and addresses of contributing authors, and include titles of submitted research proposals from interested AAFC Research Stations and their collaborators.

Part A summarizes the workshop held in Ottawa on March 2 and 3, 1995. Several research scientists from Agriculture and Agri-Food Canada and private sector representatives met to discuss the design of a National Agricultural Compost Trial to assess the impacts and benefits of applying composted source-separated solid wastes (CSSSW) to agricultural lands. These materials were considered as a resource and discussions focused on systematic research approaches to evaluate, conserve, and improve land productivity. Presentations were made by each participant and included; on-going research activities at their organization and within their region, a perspective on research activities required within each region, and current agricultural problems that the application of CSSSW could help solve. Discussions resulted in consensus regarding several aspects of the design. It was agreed that the National Agricultural Compost Trial would consist of a number of site specific studies located across the country primarily located at AAFC Research Stations. A need to provide standardized methods and protocols amongst studies was defined. Also, it was recognized that additional efforts would be required to devise an approach for data integration amongst sites. Participants agreed to submit research proposals. A distinct benefit of the workshop was to bring together local partners in the public and private sectors and this has spawned new on-going collaborations.

Part B of this report identifies the need for research on selected topics such as metals, organic contaminants, plant and animal pathogens, and various agronomic considerations.

Part C provides a conceptual framework to assess the impacts and benefits of CSSSW application to agricultural lands in harmony with regional needs and objectives. Recommendations are discussed for the use of the conceptual framework at local sites to ensure sufficient information to assess soil quality. The geographical context of CSSSW production, potential uses on agricultural lands and an example study are also included. Part C reconciles the conceptual framework with the considerations of workshop participants as presented in Part A. Specific recommendations have been made regarding the coordination and funding of the National Agricultural Compost Trial which might ensue based on joint funding under AAFC's Matching Investment Initiative Program.

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GENERAL INTRODUCTION

The Solid Waste Management Division of the Hazardous Waste Management Branch of Environment Canada contracted the Centre for Land and Biological Resources Research (CLBRR) of Agriculture and Agri-Food Canada (AAFC) to prepare a design for a National Agricultural Compost Trial (NACT) focused on assessing the soil and environmental benefits and risks associated with the application of composted source-separated organic wastes to agricultural lands. CLBRR's interest was enhanced by Canadian Council of Ministers of the Environment (CCME) program which sets the objective to reduce by 50% the land filling of waste by the year 2000 and the perceived likelihood of increasing pressure on agricultural lands to accept composted source-separated solid wastes.

A total of 162 centralized composting facilities, either in operation or in the planning stage, were identified in Canada in 1995 (National Survey of Composting Operations in Canada, 2nd edition, Environment Canada). Currently 50% of Canada's population resides in areas where composting facilities are operational. There is a growing role for composting in solid waste management. A 50% diversion, of the 22 millions of metric tonnes of waste produced by Canadians, will increase pressure on agricultural lands to accept these organic residues. It is therefore essential that the Canadian agricultural scientific community address various concerns related to this application so that food and environmental safety can be ensured.

Under intensive farming, soil quality is degraded mainly due to losses of organic matter. These degraded soils have a high level of compaction, poor water infiltration and retention, oxygen depletion and depleted fertility. The replenishment of soil organic matter by adding CSSSW may benefit degraded soils. These benefits could include: increased soil aggregation and porosity, improved soil water infiltration and retention, increased gas exchange and cation exchange capacity, improved root growth, and reduced wind and water erosion. Moreover, the restoration of soil quality will contribute to improve surface and groundwater quality and crop production. In addition to altering soil quality, CSSSW may be useful to resolve various agricultural problems. For example, agricultural wastes may be mixed with CSSSW and provide a material which is more useful than either alone. However, the CSSSW may need to be engineered to crop specific needs to avoid possible deleterious effects.

Compost is a solid mature product resulting from composting (CCME/BNQ (Bureau de normalisation du Québec) definition). Composting is a managed process of biooxidation of a solid heterogeneous organic substrate including a thermophilic phase (CCME/BNQ definition). The composting process results in a change in the organic materials leading to the production of stabilized humus. However, the production of stabilized humus is virtually impossible to attain in a practical sense. This results in variable compost reactivity with the soil-crop system. The treatment of material by aerobic decomposition has been interpreted to mean that the quality of the end-product was enhanced and the end-product was clean and sanitized.

The beneficial aspects of adding composted organic residues to soil may be counter-balanced by the risks of metal contamination, and plant and animal pathogens propagation. This is a particular concern if the source of wastes is not continuously controlled. The addition of composted organic residues may change the fragile equilibrium between soil available and non-available metal ions, nitrogen and carbon cycles, and soil microbial activities.

During an Ottawa workshop held in March 1995, a group of Agriculture and Agri-Food scientists from all regions of Canada met with selected members of the Composting Council of Canada (CCC) and Environment Canada. The purpose of the meeting was to design an agricultural trial for the assessment of and agricultural use of CSSSW. The concerns of the participants varied. Major concerns were the fate of trace elements, synthetic organics, and pathogens in composted wastes and their effects on soils, plants, animals and humans. The need to have a national database listing the amounts of CSSSW produced and their agronomic characteristics was discussed. A requirement for analytical methods to estimate the levels of nutrients and toxic components and maturity of composted wastes and amended soils was defined. In addition, participants expressed the need for research to blend, mix or co-compost different wastes to produce an engineered final product with desirable characteristics for specific agricultural and horticultural uses.

Following the workshop, the task of developing a conceptual approach, based on the consensus that arose from the workshop, was initiated. We considered the regional differences and the need for multidisciplinary studies. The aim was to provide a coherent development suitable to local, regional, and national assessments of change in soil quality associated with CSSSW application. The approach had to include procedures; to measure changes over time and location, and to serve as a model for measures of change in water and food qualities.

We recognize that the maintenance of soil quality for the production of food and fibre crops ultimately rests with the producer. It was therefore critical that the development of capabilities for national assessments be complemented with capabilities to assess soil quality under various farming practices so as to more directly serve landowners and local communities.

Research activities related to the valorization of composted non-agricultural and agricultural waste are going on at various levels in the Provinces of Canada. More than 50 projects are actually in progress or completed in Quebec, and a somewhat similar effort but less intensive, is going on in other parts of Canada. The reality related to management of physically and chemically degraded soils vary significantly across the various regions of Canada. The chemical composition and the maturity of compost vary also across the country. Due to the great diversity of soil problems and compost materials, these trials should focus on the local interests. The integration of the gathered information may not be possible beyond the regional level. In general, the experimental design should be developed to include aspects such as, nutrient availability, crop yield and quality, physical and biological aspects related to soil health and finally, water quality emphasizing the leaching of metal ions and organic contaminants. These aspects should be the main focus in conjunction with climate, soil type, texture, tillage practices and crops grown.

The objectives of this contract were to develop a design for a National Agricultural Compost Trial for CSSSW and to develop a research working group across the country in partnership with CCC members to address regional and national issues related to the agricultural use of these exogenous composts.

PART A: REPORT ON THE WORKSHOP ON CSSSW APPLICATION TO AGRICULTURAL LANDS

INTRODUCTION

In the fall of 1994, CLBRR was contracted by Environment Canada (EC) to design a National Agricultural Compost Trial (NACT) concerning the application of Composted Source-Separated Solid Wastes (CSSSW) to agricultural lands. As part of the CLBRR's effort a workshop was held in Ottawa on March 2 and 3, 1995. Participants of the workshop (Appendix 1) represented the various regions of Canada and included at least one AAFC scientist and one industry or university associate and member of the CCC actively involved in related activities. Other research scientists from AAFC, staff from EC and CCC, university scientists, and industry and municipality representatives also contributed. A series of presentations were made on regional issues and interests by the regional representatives. They outlined current related research activities, regional concerns regarding land applications, and agricultural problems which might be alleviated by land applications. Considerable discussion was focused on developing a consensus; what research activities are required before land application could be recommended, what research strategies and approaches would be the most useful in assessing impacts and benefits, what methods should be used to integrate data from across the country, and how should the NACT be coordinated and funded.

Richard Asselin, director of CLBRR, opened the workshop by welcoming participants and congratulating them on their interest to transform a waste problem into an opportunity to obtain potential benefits from these organic wastes by application to agricultural land. He presented to participants the challenge of defining the parameters to ensure the applications to agricultural lands could be done in a sustainable manner. He spoke of the need for an authoritative document outlining best practices so that land application was environmentally friendly, socially acceptable, economically viable and provided safe crops and agricultural products.

Background

EC and CCC are promoting Source-Separated Organic compost as a resource. Gordon Owen, Environment Canada, explained his involvement in the CCC and EC's National Compost Program. In EC's view, composting is not simply a process to reduce land fill but also an activity to extract a valuable resource from the waste stream and relocate the value to land. EC promotes compost with the caveat to protect the environment. The focus of EC's National Compost Program is to develop the use of composted and highly organic materials to improve the soil resource and divert waste. It consists of four components; information, standards, research coordination and demonstration. The program provides and coordinates information (e.g., Annual Proceedings of CCC), develops and promotes national standards for compost quality (e.g., EC coordinated efforts with CCME, BNQ, and AAFC to provide a voluntary National Compost Standard), coordinates research on compost (e.g., maturity tests and compost as a biofilter), and demonstrates and promotes the use of compost throughout Canada (e.g., National Compost Awareness Week and development of the NACT).

Peter Meyboom, Executive Director of CCC, explained that the CCC is a national non-profit corporation mandated to advocate the use of composting as a way of converting waste to a resource. The membership has equal parts industry and government members including all major municipalities of Canada. The CCC has a strong scientific component in the membership, and is a unique organization in that both regulator and regulated sit at the same table.

The Research Branch of AAFC is mandated to provide information and technology to conserve and improve land productivity and to ensure the quality of soil resources and the safe production of food and fibre crops. AAFC perceives that there is a growing pressure on agricultural lands to accept these materials. This pressure results from the following: CCME requirement for 50% diversion from landfills by year 2000, restricted use of incineration for disposal of organic wastes, recognition that composted municipal and industrial solid waste is a highly organic material that could be considered a resource useful for restoration of degraded soils, a new National Compost Standard has been prepared and could be used to declare CSSSW materials as safe for agricultural lands, municipality concern over the cost to haul organic waste materials to disposal sites. An estimated 8 million tonnes of CSSSW could be headed to Canadian agricultural lands each year.

The impacts of CSSSW amendments on agricultural soil is undetermined. EC and CCC are taking a very responsible approach: they feel that they have a resource which is useful, that there is a place for it on agricultural land, they have come to AAFC and asked for a study design which would ensure that these materials will be used in the right way.

Definition of materials

Municipal and/or Industrial solids in origin, they were source-separated from garbage waste stream, have been composted or co-composted, they are highly organic, often contain a large portion of leaf and yard wastes or a specific industrial waste such as pulp and paper sludge, meet Category A designation in the National Compost Standards as defined by CCME/BNQ standards, may contain food wastes, and may be combined with agricultural wastes to solve an agricultural issue.

Purpose of the workshop

The purpose of the workshop was to develop a consensus for the design of a multi-disciplinary and multi-site scientific study to assess the soil and environmental risk associated with and the benefits of composted source-separated solid waste as an amendment for Canadian agricultural soils.

REGIONAL PERSPECTIVES

The participants were divided in four groups: Maritimes/Quebec, Ontario, Prairies, and British Columbia. Participants at the workshop provided a brief summary of current regional research activities and interest related to agricultural use of CSSSW and other composted organic materials. The information in this chapter was provided by the participants at the workshop. The information presented here does not necessarily reflect all the on-going related activities in a given region but does represent the perception of the participants. In addition, one should also note that the majority of research activities reported herein are related to composted agricultural waste. This is the case for at least two reasons. Many of the participants work for AAFC and have focused on agricultural wastes. Also, source-separated solid waste material from the industrial and municipal stream has not been as readily available for land application.

Maritimes / Quebec

(Perspective provided by D. Grimmer, J. Richards, C. Bourque, V. Rodd, R. Halsey, R. Simard and F. Forcier).

In Prince Edward Island, there is an interest to use composted materials to rehabilitate soils which have been degraded by poor management. Soil type and landscape form coupled with potato production and poor selection of crop rotation, e.g., barley/potato, have resulted in high rates of soil erosion and degradation. An agricultural trial using composted potato waste and wood ash in a potato/barley/clover rotation experiment has been going on for three years. The results indicate that 25 tonnes/ha of compost are required to produce a full crop. At this rate of application farmers would choose chemical fertilizers for cost effective fertilizer application. As potato hull compost has only 1% N, co-composting with more nutrient rich wastes is recommended. There is growing interest to use compost to develop a processed topsoil to substitute for the natural topsoil in landscaping activities and to restore land that was stripped.

In Nova Scotia, the city of Lunenburg is diverting 75% of their organic wastes through composting and use by landscapers. Other composting activities are related to recycling forage and manures (4 projects), and frozen food processing wastes. The objective of these activities was to evaluate the effects of rate and time and frequency of application, on the distribution of N in the soil profile and ammonia volatilization.

In New Brunswick, research activities are related to the mobility of metals and other chemical contaminants, and on methodology to assess impact on the environment. Water erosion, due to high rainfall and steep slopes, is a major cause of soil degradation. Organic residues, composted or not, are of interest for mulching and for improvement of physical and chemical properties in coarse textured soils. Pulp and paper mill residues are being applied on agricultural lands by the pulp and paper mill industry to demonstrate their potential benefit to improve soil productivity.

In Quebec, agronomic evaluation of more than 30 composts for wheat production is underway. The main research interests are the impact on yield, nutrient uptake, protein quality and the fate of N. Research also considers the effect of compost addition on soil enzymes. From these trials, researchers expect to develop a strategy to maximize the use of nutrients for wheat production and to decrease root diseases and weeds. Other activities include the use of biosolids in sod production, on-farm composting, methods for composting municipal solid wastes, composting and direct land application of de-inking residues and pulp and paper mill residues, and characterization and impacts of composts on soil and plant quality.

In the Maritimes/Quebec region, the major concerns associated with the use of compost are related to the contamination of soils and water by metals and chemical contaminants, especially in acidic soils and the dissemination of plant and animal pathogens in the human food chain. On eroded coarse textured soils, these organic additions are expected to reduce soil erosion and improve water holding capacity and cation exchange capacity. In the fine textured soil, organic additions are expected to improve soil aggregation and thereby improve water movement and retention, and soil aeration. It was recognized that research should be oriented toward developing a strategy for making better use of compost nutritive value and the potential capacity for limiting leaching of P and K. The compost industry seems to be more and more interested to combine municipal solid wastes with sewage sludge to produce a soil blend that can be used as a replacement for natural topsoil.

Ontario

(Perspective prepared by J.D. Gaynor, C.F. Drury, C.S. Tan and T.W. Welacky).

The Essex region has been actively involved in programs to reduce the quantity of material land filled. Cardboard, tires, wood products, and to a limited extent, sewage sludge have been diverted from landfills. Waste reduction by burning has also been implemented. Aluminum, paper, used motor oil and plastic wastes are being recycled. Household wastes are being composted in backyard recyclers for utilization in home gardens and flower beds. Research is now being directed to reduction of curbside waste by separation and composting.

The Essex-Windsor Solid Waste Authority has initiated a pilot project on the feasibility of centralized and decentralized collection of curb wastes. The material is separated and composted, and utilized in parks and recreational areas. It is projected that the Windsor Public Utilities Commission can accommodate the expected volume of composted waste from this region for a number of years. Thus, little interest was expressed for utilizing compost on agricultural land. A local environmental corporation receives unprocessed waste from a food processor. The material (about 10,000 tons per year) is currently disposed on agricultural land. Other technologies including composting are being considered.

A London based environmental group is processing curb waste for agricultural use, however, only limited markets have been established. Paper sludge waste is being produced with the intent to evaluate the material suitability as an agricultural amendment at several sites in Southern Ontario.

In Ottawa, curbside waste is now collected regionally. Leaf and yard wastes constituted about 14% of the collected wastes. Between April and November about 30,000 tons were collected and 16,000 tons are currently composted with or without sewage sludge using passive aeration technology.

In Eastern Ontario, there is direct land application of sewage sludge and pulp and paper mill sludge. The pulp and paper industry have initiated these activities in collaboration with Kemptville Agricultural College and agricultural producers willing to participate in the trial.

At Harrow, researchers propose to evaluate the response of field and vegetable crops to finished compost. Changes in soil properties such as bulk density, water stable aggregates, nutrients, water holding capacity and organic matter quality will be evaluated to determine soil building or enhancement characteristics of the material. Optimum rate of application for selected crops will be determined.

In Ontario, the soil situation is similar to Quebec, in that both fine and coarse textured soils are found. In coarse textured soils, the problems are related to a deficient water holding capacity, acidic pH and low buffering capacity, and low organic matter content. In fine textured soils, a lack of structural stability results in poor water infiltration and retention capacity and gases exchange capacity. Thus, in both cases, organic residues may contribute to restore and maintain sustainable agriculture.

The impact of CSSSW on agriculture is unknown. The finished product will need to be evaluated for its nutrient or soil amendment characteristics to determine marketing strategy. The major concerns for CSSSW utilization is marketability and environmental and health risks. Users are cost conscious with little interest in purchasing soil amendment materials. The heterogenous nature of the material will require chemical analysis of each batch of finished product for fertilizer value and metal content. From these evaluations, the value for agriculture and crop selectivity will need to be determined.

Prairies

(Perspective provided by D.M. McCartney, J.J. Leonard, T. Clark, F. Larney, R. Morrell and V.O. Biederbeck).

In the Prairies, the interest for composting is different than for the other regions of Canada because of the huge agricultural areas and relatively small cities. Organic residues are expected to assist in solving several problems: wind erosion in coarse textured soils, salinization of soil and water resources, and leaching of agrochemicals on irrigated land.

The city of Winnipeg is interested in biosolids and leaf and yard wastes composting. In addition, Manitoba emphasis is on controlling odour and pathogens related to hog manure disposal either by composting or direct land application.

Saskatchewan municipalities are interested in reducing transportation cost associated with hauling wastes. Several locations compost their organic residues to reduce the volume of organic waste materials. Co-composting municipal solid wastes and pulp mill waste, fish plant, wild rice hulling plant waste with sewage sludge and leaf and yard wastes are being considered. Other sources of waste are feedlots and ethanol plants. With the heterogeneity of feedstock, the main concern is the quality of compost and its effect on the various crops and soils.

At Swift Current, oily waste sludge was applied to sandy soil and results indicate that the waste was effective in improving the production of wheat. This work suggests that land application could dispose of 5-10% of the waste produced by the production of 16,000 barrels of crude per day.

In Alberta, composting activities are mainly oriented toward agricultural waste, especially manure. There are several research projects: evaluation of the nutrient retention efficiency of compost-based management of dairy manure, the study of the effect of cold temperatures on composting processes, and determination of the factors that affect physical properties of compost so that they can be controlled and manipulated in the optimization of composting processes. In addition, the city of Edmonton has approved the construction of a composting plant for municipal solid wastes and will use the compost for the reclamation of contaminated sites.

Major concerns in the Prairies are related to the potential causative factor in pollution of soil, and surface and subsurface water resources. This is especially the case where irrigation is used. Information is needed concerning nitrogen leaching, salt concentration, and other pollutants following annual application of CSSSW on soil deprived of organic matter.

British Columbia

(Perspective prepared by G.H. Neilsen, J. Paul, E. Hogue and D. Neilsen).

With the widest range of climate in Canada, a similar wide variation in crops occurs in British Columbia. Most of the intensive animal agriculture in British Columbia is located in the Fraser Valley (82% of the poultry, 67% of the dairy cattle and 72% of the province's hogs). The use of municipal or industrial wastes is limited and is not being encouraged for application on agricultural land because of the large surplus of animal manures. Some composted municipal waste and sewage sludge from Vancouver are being applied to agricultural soil in Delta area. There is, however, scope for application of considerable composted waste (currently composted poultry manure) for raspberry production in the Central Fraser Valley. A major concern in this region is N mobility due to widespread NO_3-N contamination of groundwater in the Abbotsford aquifer and the high leaching potential of the considerable winter precipitation. The static aerated compost facility at the Agassiz Research Centre is suitable for research on the composting process.

In contrast, in southern interior British Columbia, a semi-arid climate prevails and soils are generally coarse textured, and infertile with low organic matter content. Presently, the Greater Vancouver Regional District (GVRD) has research demonstration plots involving the application of biosolids to dryland range and mine tailings in the Princeton area. In addition, about two thirds of the irrigated soils planted to high value horticultural crops (tree fruits, wine grapes, ginseng, etc.) are coarse textured with poor nutrient and water holding capacities with a known susceptibility to trace element deficiencies.

In 1993, randomized replicated field plots were established at the Summerland Research Centre to test the use of seven different municipal biosolids, food, yard and other composts as to suitability for use as soil amendments. Yield, nutrients and trace element uptake of carrots and chard have been monitored and soil samples collected for soil quality changes. In addition, in 1994, two new field trials have been established. At the Summerland Research Centre, application of GVRD-municipal biosolids and a waste paper mulch are being compared for effect on various soil quality parameters and growth and nutrition of apple trees. In an "organic" vineyard as normal "certified organic" practices (check) are being compared to application of municipal and hog manure composts.

Cumulative evidence from the Summerland Research projects to the present has indicated that waste amendments increase water holding capacity, plant available water and pH buffering capacity of sandy soils. Wastes can provide a similar benefit as peat in reducing the severity of apple replant disease. This suggests a possible market for organic waste including high grade composted municipal solids, biosolids, etc. to improve the physical condition and fertility of the two thirds of soil used by the high-value horticultural industry in southern British Columbia which have coarse texture and poor nutrient and water holding capacities.

The major development needs regarding compost in British Columbia are: to design composts for specific needs, e.g., as a planting hole amendment for fruit growers or as an organic fertilizer for organic growers, and to demonstrate the use of compost additions to counteract soil degradation with demonstration of crop benefits for high intensity production. In addition, major research is needed to determine the mobility of metals in the environment and to determine the mobility of nitrogen to groundwater when applied as organic N. It is important to reduce such leaching due to widespread elevated N concentration of groundwater in the populated areas of British Columbia.

CONSIDERATIONS OF THE NATIONAL AGRICULTURAL COMPOST TRIAL

Several issues were discussed during the workshop in order to develop a consensus amongst the participants. In general it was difficult to develop a consensus of agreement as the participants had different perspectives and regional concerns. The questions that follow represent the nature of these discussions and provide a perspective for a more complete understanding of recommendations for the NACT listed in Part C. Clearly there were more questions than answers.

How would sites and partners for the NACT be selected?

1) Should there be a number of sites representing different climate, soil and landscape properties, and land-use and management systems?

2) Should sites be located only at AAFC research stations?

3) What proximity should the site have to suppliers of CSSSW?

4) Are there information systems which would be useful in the selection of sites and provide a rational for site selection?

What would be an operating definition of the materials we would include in the NACT?

1) What types of materials should be included and should co-compost or mixes of different waste streams be included? The answer to this has several practical aspects especially in terms of the physical location of waste providers, composters and agricultural lands.

2) Should the materials applied to agricultural lands be classified by the newly developed National Compost Standards? If these standards are accepted there would be an expected long term lifetime of these standards and a record of any changes in the standard. Therefore any studies done in the near future would have a reference document which would refer to the quality of the compost material. However the certification and permit for land application are a provincial jurisdiction and most provinces

have various existing and different guidelines.

3) Will the category of compost selected for the NACT influence the requirement for and direction of the research? For example, if Category A compost standard is selected do we need to study metal issues?

4) Should the NACT include a range of compost qualities? If so then the research requirements may be more extensive and the benefits of the findings may be of interest to a greater audience and more applicable.

5) Will the category of compost selected for the NACT be available for all sites? Some interested industry partners may not be able to generate the selected quality of compost.

6) Will the future monitoring of compost producers and applications to agricultural lands be thorough enough to ensure that any recommendations from the NACT regarding the suitability of compost will not be mis-represented? For example, if the NACT recommends compost application to agricultural land does this mean that any compost will be applied?

7) Will CCC be a proponent of the study regardless of the compost quality that interested industry participants provide?

Can a standard compost be defined for application at all sites?

1) Can all producers of compost in the NACT provide the same mix of components for the composting process and ensure a similar degree of compost maturity and supply? If not then the expense to ship materials across the country would be prohibitive.

2) Does a standard mix represent the compost which the industry will produce in quantity and supply for agricultural land application within their future market?

What research is required before the addition of these materials to agricultural land can be recommended?

1) What approach should be used to assess impact and benefits?

2) What are the soil, air, water, agronomic and health issues that should be addressed in the NACT?

3) Are there regional differences in the type and detail of research required to assess the impacts and benefits of CSSSW applications to agricultural land?

4) Can a standard experimental design be defined which would be used at all sites? For example, should the same crop be grown at all sites?

5) Can an experimental treatment be designed for all sites which would be used to reference other site specific experimental treatments?

6) For how many years should an assessment be planned?

What need is there for integration of data amongst the various sites?

1) Is it appropriate to integrate across large land masses with distinctly different agroecosystems?

2) Are there existing databases which can provide a reference for the data collected in the NACT and enhance the understanding and conclusions of the NACT?

3) Are there methods to allow extrapolation from sites to regions and what are the concerns in scaling-up?

4) Can a minimum data set, which should be collected at each site, be defined? The intent is to determine if a baseline and minimum data set should be established and declared a must for all sites to be included in the NACT. The purpose of such a data set would be to declare what soil, water, air, and agronomic related data should be collected. In order to do so, a consensus on what are the soil, water, air and agronomic issues would be required.

5) Should we aim for a soil suitability rating which would indicate which soils in Canada would benefit from the addition of these materials?

6) Can a standard set of protocols for sampling and analysis be established so that all participants in the NACT would be able to compare data? This does not necessarily require that a minimum data set be collected at each site. A standardized protocol would be useful on its own. In addition it would allow comparison in time and across studies.

How should the NACT be structured, coordinated and funded?

1) Should there be a centralized coordinating effort? This would be required for several reasons including distribution of centralized funds, reporting, data integration, and promotion. This may not be acceptable and may carry a stigma related to "centralized". Can funds be generated to support a centralized coordinating effort?

2) Can enough funds be generated to support several locations with comprehensive research activities?

4) What procedures should be followed to make the best use of AAFC's MII funds?

What are the constraints to the NACT?

1) Can enough resources from all partners be obtained to carry out a multi-site assessment?

2) Can a firm enough commitment be obtained from the various partners to initiate and then carry out a multi-year assessment?

Consensus of the CSSSW workshop

Participants agreed that the NACT would consist of a series of site specific studies which would be more or less coordinated. The NACT would have a national focus at least in terms of studies taking place across the country with annual meetings to discuss progress. AAFC scientists and their partners agreed to submit research proposals and to develop funding opportunities. It was recognized that several issues were not resolved by our deliberations and that a different approach than that taken at the workshop would be required to develop a NACT design.

PART B: ISSUES RELATED TO CSSSW APPLICATION TO AGRICULTURAL LANDS

INTRODUCTION

The agricultural uses of exogenous sources of organic matter to replenish depleted soils have been a controversial issue due to the potential for contamination associated with these materials. The lack of attention paid to the sorting of wastes (domestic and industrial) at the source, coupled with poor composting technology, has contributed to the development of this poor image. With the CCME objective to reduce land filling by 50% by the end of this decade, municipalities and industries of Canada have to develop new approaches to collect and handle organic wastes. Composting facilities and recycling through land application are an alternative. We must understand and contribute to the production of good compost by placing a serious effort on the supply of high quality (contamination-free) feedstocks rather than assuming that the composting process can be a substitute for our "laisser-aller".

These exogenous composts contain mainly organic matter and water which may be contaminated by metals, organic contaminants and also may support the development and diffusion of animal and plant pathogens. Research on these exogenous organic sources is required to ensure that they do not significantly modify the short and long term bioavailability and migration of metals from composts or the soil matrix through the soil profile. Another aspect of concern is the proper assessment of plant and animal pathogens spreading by short and long term compost application. Other questions related to nitrogen mineralization dynamics and accumulation of phosphorus and potassium following compost application need to be better understood.

The objective of this chapter is to discuss the potentially short and long term impacts of compost application on the bioavailability and mobility of metals and organic contaminants, the spreading of pathogens in cultivated soils and various agronomic factors. Although the composts produced from source-separated solid wastes are expected to reduce the negative impacts related to metals and organic contaminants, the need remains for research on aspects related to increased mobility of metal ions and pathogens spread.

METALS AND ORGANIC CONTAMINANTS (Bourque, C.)

Metals

One of the most contentious issues with respect to compost utilization is that of possible metal contamination of the environment. Most of the compost produced in North America in the past was derived from sewage sludge feedstock. Many of the concerns were associated with this relatively contaminated feedstock.

During the past ten years, there has been a shift towards compost produced from source-separated municipal solid wastes (MSW) and from other "clean" organic wastes. As well, sewage sludge metal levels have in general decreased (Ryan and Chaney, 1993). The compost produced will play an important role in agricultural utilization if environmental and economic concerns can be met.

The Canadian Council of Ministers of the Environment (CCME) and the Bureau de normalisation du Québec (BNQ - member of the Canadian Standards Association) are in the process of developing compost quality guidelines (Draft Guidelines P 1923-410). The approach for metal limits has been that of "No net degradation". The maximum limits proposed are the least severe of: i) British Columbia Regulation 334/93 - "best achievable limits" or ii) soil average concentrations plus three standard deviations for Alberta, Ontario and Quebec soils. These limits are relatively severe when compared to guidelines from other jurisdictions. They are also much more restrictive than sludge guidelines. For example, proposed CCME values for Cd and Pb are 3 and 150 mg/kg DW (dry mass), as compared to 34 and 1100 mg/kg DW for the Ontario sludge guidelines.

The United States has not yet developed MSW-compost standards. It has developed sewage sludge standards (applicable to composted sewage sludge or sewage sludge) under the Clean Water Act EPA 503 regulations. The approach taken was that of "No observed adverse effect levels" (NOAEL). This approach assessed 14 risk pathways (e.g., sludge-soil-plant-human). The levels permitted are significantly higher than those in the CCME/BNQ guidelines. For example, Cd and Pb limits are 25 and 300 mg/kg DW, respectively (see above). It is likely that in the near future, most states will apply EPA 503 regulations to compost utilization (T.J. Logan, Ohio State University - personal communication).

Because of the historical background, most of the guideline values for metals are based on research involving land application of sewage sludge or composted sewage sludge.

Relatively little research has been carried out using MSW-compost. In addition, little is understood of the fundamental processes involved when organic matter is added to soil. The addition of compost to soil is likely to alter the speciation and hence the mobility and bioavailability of metals already present in the soil, and perhaps of the metals present in the compost. Will these changed soil dynamics have environmental and agricultural consequences? How significant are these consequences? More research is needed to better understand the fundamental mechanisms involved. Many issues have been discussed. The most important would appear to be metal bioavailability, soil degradation, phytotoxicity, metal effects on biota, and metals to be monitored.

Metal bioavailability/plant uptake

The major concern with respect to metals is ultimately bioavailability - can these metals become available to humans and other living species and what are the effects? This bioavailability will depend on many factors - concentration levels, presence of binding materials (e.g., clays and humus), soil type, pH, salt concentrations, etc. Many pathways can be envisioned - uptake by plants, animals, earthworms, airborne dust, groundwater, and surface water.

Sludge studies by Bidwell and Dowdy (1987) and by Chang *et al.* (1987) have shown that plant availability of sludge-borne metals is greatest during the first year after application. This is contrary to the belief that mineralization will result in increased plant uptake with time. These observations may be due to the binding capacity of the inorganic fraction of sewage sludge - Fe and Mn oxides, carbonates, phosphates and sulfates. Corey *et al.* (1987) indicated that some sludges could be so low in metals and so high in adsorption capacity that addition of sludge would actually reduce metal uptake by plants. However, the adsorption capacity of MSW-compost may be significantly different and hence a different behaviour may be observed. It is important not to extrapolate unknown MSW-compost behaviour to known sewage sludge behaviour. These may be very different. In fact, compost is not a uniform product. Each compost produced may be significantly different in nature, depending largely on the source materials used. Further research is needed to assure proper agricultural utilization and to avoid pitfalls of improper use.

Soil type and soil pH are known to play an important role in metal ion mobility and plant uptake. As pH decreases below 5.5, metals are desorbed and ion-exchanged from organic and inorganic sites. Little is known on the short-term and long-term fate of metals present in MSW-derived composts. The ease with which metals could be leached was found to differ significantly, depending on the metal being considered (Bourque *et al.*, 1994). The relative risk of groundwater contamination and plant uptake will depend in part on the speciation of the metals present in the compost. Since Fe and Mn colloids are known to be important factors in metal adsorption, their role cannot be overlooked. The addition of organic matter to soils and their subsequent mineralization may alter the mobility of species present. The possibility of metals being leached and contaminating surface and groundwaters must be evaluated to address public concerns.

Soil degradation

With the mineralization of the organic matter present in compost or sewage sludge, metal build-up can occur with repeated land application. McCalla *et al.* (1977) studied Cd build-up from repeated sludge utilization. At an annual application rate of 6.7 Mt/ha, they reported that in "excess of 60 years of continuous application was required before the mixed 15 cm zone of incorporation is 50% sludge". Depending on the concentrations, the rates of application and the rates of mineralization, loading with subsequent soil degradation could occur. The proposed CCME/BNQ guidelines have thus incorporated maximum cumulative rates (kg/ha DW). It has been argued by Chaney and Ryan (1993) that the "potential for adverse effects from metals should be the basis for concern, not simply their presence" (i.e. risk assessment). More information may be needed to assess metal build-up concerns from MSW-compost utilization.

Phytotoxicity

Although a few cases of phytotoxicity have been reported for composts derived from high metal-level sludges applied at low pH, the two most persistent problems reported have been with boron toxicity and manganese deficiency (Chaney and Ryan, 1993). Boron can be present in MSW-compost at relatively high concentrations. Detergents and glues found in cardboard are thought to be important contributors. Boron phytotoxicity from MSW-compost was first reported by Purves (1973) and several other examples have since been reported. Bean is known to be especially sensitive to B. It is also known that this phytotoxicity is usually short-lived due to the leaching of the soluble boron species. Volk (1976) reported that B-toxicity occurred only during the first year of application and that soluble B was leached out of the root zone over winter. Other metals (e.g., Cu, Zn, Ni) may demonstrate phyto-toxicity if present at high concentrations and applied to sandy soils at low pH (Ryan and Chaney, p. 442, 1993).

Compost made from MSW usually raises soil pH due to the presence of $CaCO_3$ and other lime equivalents. In soils low in Mn, this rise in pH has been reported to immobilize Mn, leading to Mn deficiency (Andersson, 1983). This would appear to be a problem, only in manganese-deficient soils and can be remedied by adding Mn to the MSW to be composted. Another factor not fully understood is the duration of the phytotoxicity which may be of short duration (e.g., B) or persist for longer periods.

Effects of metals on biota

There are several issues that may be of concern. First, earthworms are known to be bio-accumulators of Cd, Pb and PCB's (Ireland, 1983). This may represent a risk to wildlife that consumes worms (e.g., birds, shrews, moles, etc.). Herbivores, who do not participate in this bio-accumulation pathway, are generally considered to be at less risk. There have also been reports of metal effects on microbes. Most of this work involved sewage sludge. Brookes and McGrath (1984) identified adverse effects of sludge-applied metals on the Rhizobium strain which forms nodules in white clover and related species. Relatively little work has been carried out on MSW-compost and possible effects on the microflora. Another concern may be bio-transformation of metals present in compost and in soils (e.g., methylation of Hg and Pb).

Metals to be monitored

Funding may not permit monitoring of all metals of interest. The following metals are part of the proposed CCME/BNQ guidelines: As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se and Zn. In addition, B (phytotoxicity) and Fe and Mn (mobility effects) may be of concern. Much attention has been paid to Cd. Chaney and Ryan (1993) have concluded that MSW-composts "comprise no Cd risk" when present at NOAEL concentrations. However, concerns with respect to Cd contamination are certain to persist. Lead risks have also been evaluated. The main risk would appear to be from soil consumption by children or from dust particles being inhaled (Chaney *et al.,* 1989).

Another issue is the methodology used in monitoring metals. A CCME/BNQ sub-committee has recently prepared proposed analytical protocols (Draft proposal). These methods are mostly derived from those used to analyse sludge. The values obtained will be influenced by the methodology used. For example, research (not yet published) has shown that metal numbers obtained via the Mehlich extraction procedure (used by several soil testing laboratories) were lower than those obtained using the CCME/BNQ "Draft proposal procedure". It is important that analytical methodology be consistent when setting up comparative research studies.

Organic contaminants

Organic contaminants appear to be of less concern than metals. The CCME/BNQ draft guidelines initially included only PCB's (total limits of 5 and 10 ppm) and PAH's (total limits of 100 ppm) and these were removed during the review process. A review by Williams (1988) on sludge utilization guidelines for the European Community contains no mention of organic contaminants. A paper by Sauerbeck and Leschber (1992) indicates growing public concern, and that maximum permissible concentrations have been proposed for a revised German sewage sludge regulation for organohalogens, PCB's, dioxins and furans. European standards for MSW-compost do not yet contain limits for organic contaminants (DeBertoldi *et al.*, 1990). There would appear, however, to be growing concern for evaluation of possible organic contaminant effects from both sewage sludge and MSW-compost application to agricultural soils.

In Canada, studies conducted at the Wastewater Technology Centre indicated no detectable plant uptake of selected PCB's, PAH's and phthalate esters from soils containing 1% DW of sludge and up to 10 mg/kg of contaminant. Webber and Lesage (1988) reported analytical problems and generally low concentrations when measuring organic contaminants in 15 Canadian and 34 Ontario sludges. PCB's were typically less than I mg/kg DW. Dioxins and furans did not exceed 0.3 µg/kg DW. Pesticides seldom exceeded 1 mg/kg DW and were typically <10 µg/kg DW. The US EPA 503 risk assessment of sludges notes that two pathways represent the greatest danger: i) direct ingestion of sludges by children and ii) adherence of sludge to forage/pasture crops from liquid sludge application. Obviously, the second pathway is of less concern with MSW-compost.

The issues of concern for organic contaminants are much the same as those for metals - fate in the soil environment, plant uptake, bio-accumulation, leaching into surface and groundwaters and phytotoxicity. The compounds most likely to be of concern are the following: PCB's, PAHs, other chlorinated hydrocarbons and certain pesticides.

Little is known of organic contaminant fate during the compost process. It is reasonable, however, to expect that many organic contaminants will either be biologically or thermally decomposed. A proposal by the CCME/BNQ Committee is that "monitoring of sludges and composts for the EMPPL priority pollutants be undertaken to obtain a reliable database for organic contaminants in these materials". It is obvious from these and other reports that more research is needed before an assessment of organic contaminant effects can be made.

Research needs

Many of the above issues are interrelated. As already noted, most of the research carried out in the past utilized sewage sludge. CSSSW may demonstrate very different behaviour. A prioritized list of research needs for both metals and organics could be as follows:

1) Metal/soil/organic matter interactions using CSSSW. These interactions are varied and contain many facets - bioavailability, plant uptake, mobility, leachability, synergistic and antagonistic effects, speciation, competition for adsorption sites, etc.

2) Effects of soil characteristics and pH on metal mobility and bioavailability.

3) Effects of repeated applications over time - are there build-up concerns?

4) Assessment of the fate or organic compounds during the compost process.

Can contaminants survive the compost process intact?

5) Effect of feedstock materials on behaviour outlined in items 1-3.

6) Assessment of phytotoxicity of CSSSW, with particular attention to boron and manganese.

7) Assessment of possible effects on biota, paying particular attention to the earthworm pathway.

8) Assessment of the fate of organic compounds when introduced in the soil environment.

PLANT PATHOGENS

(Paulitz , T.C. and M. Paré)

Plant pathogens are one of the three main pests of agricultural crops. The others are insects and weeds. Plant pathogens are microorganisms that cause plant diseases. It is estimated that plant diseases cause approximately 12% of crop losses world-wide, along with 12% losses from weeds and 12% losses from insects. Certain crops, such as potatoes, are even more susceptible to disease, and 22% of the world's crop was lost due to disease. To control plant diseases, $1 billion per year are spent on fungicides, $470 million in the United States alone. In Canada each year, nearly 6.9 million acres are treated with fungicides or insecticides, with $721 million spent on all pesticides, including herbicides.

Four types of microorganisms can cause diseases of plants. These are fungi, bacteria, viruses, and nematodes. These organisms parasitize plants. They infect the plant, use the plant as a source of food, reproduce themselves, and destroy the plant. The use of CSSSW on agricultural lands has a potential impact on two important parts of the life cycle of the pathogen - survival and dissemination.

Survival of plant pathogens

The part of the pathogen that comes in contact with the plant to infect and cause disease is called the propagule or inoculum. In northern temperate climates such as Canada, plants are infected during the growing season in the spring and summer. Once the pathogen has infected the plant as a parasite, it will grow in. and colonize the plant. After the plant has been killed by the disease or dies due to natural senescence (old age) at the end of the season, many pathogens can continue to grow on the dead plant as saprophytes. This means that they can grow on dead matter and reproduce themselves. When conditions become cool in the fall, the pathogen produces survival structures that can survive the harsh conditions of winter (both freezing and drying) and competition from other soil flora and fauna that also colonize the decomposing plant. This is crucial to the disease cycle of most soilborne pathogens - the inoculum that will cause disease the next season is produced and survives in the infected plants of the previous season. Thus, CSSSW may contain propagules of plant pathogens, either from diseased yard, lawn, garden, and park wastes, or diseased agricultural wastes.

Fungi

Fungi are multicellular organisms that grow as tiny, microscopic threads or filaments called mycelia or hyphae. These hyphae are fairly thin-walled, sensitive to extremes of heat and cold, and susceptible to attack from other microorganisms. In their actively-growing state, fungi need a minimum level of moisture and are sensitive to drying.

However, fungi could potentially survive as dormant mycelia protected inside thick plant tissues such as roots, stems, bark, or buds. In milder climates, this is a primary means of survival. Fungi also produce spores for reproduction. The spores can land on the plant, germinate, penetrate the plant, and initiate an infection via hyphae. The most common type of asexual spore is called the conidium. It can also function in survival if it forms a thick wall around it. Fungi can also produce sexual or asexual reproductive spores specifically for survival. These have a number of characteristics designed to maximize survival:

- Thick impermeable walls - to prevent loss of nutrients and water and to prevent other microorganism and soil invertebrates from penetrating and destroying the contents of the spore.
- Dark, melanized walls - melanin is a protective substance which prevents other microbes from degrading and breaking down the spore wall.
- Dormancy - the fungus has a very low level of metabolic activity and is in a resting state so it can survive for a long time without outside nutrition.
- Resistance to environmental extremes - both temperature and moisture.

The reproductive spores are often formed within infected plant tissue. In some fungi, spores are formed inside of a larger structure or fruiting body. Fruiting bodies function as survival structures. Finally, some fungi can form large, multicellular aggregates of thick-walled cells with a hard outer covering. These are called sclerotia. Most of these structures and spores are formed in association with infected plant tissue.

In summary, when conditions become unfavourable for growth either due to cool conditions in the fall or depletion of their nutrition from the plant, fungi can convert themselves into a survival form that may resist decay or breakdown in composting.

Bacteria

Fortunately, most plant-pathogenic bacteria are not as resistant as fungi. They grow as single cells and reproduce by dividing to form new daughter cells. These thin-walled cells are sensitive to drying and high temperatures. The most important genera of gram negative plant-pathogenic bacteria, such as *Pseudomonas,, Xanthomonas, Erwinia,* and *Agrobacterium* do not form spores - that is, thick-walled cells that are resistant to environmental extremes. They survive as cells in plant parts and most do not survive well in the soil. The only exceptions are *Agrobacterium tumefaciens, Pseudomonas solanacearum,* and a few other wilt-causing bacteria. The actinomycete genus *Streptomyces,* which causes scab diseases on potatoes, can also survive well in the soil, and is more resistant to environmental extremes. Two spore-forming genera, *Bacillus* and *Clostridium,* are considered fairly minor pathogens. In summary, bacteria survive primarily in host tissues such as roots, stems, tubers, bulbs, and seeds.

Viruses

Viruses are not really living entities but are infectious particles of nucleic acid surrounded by a protein coat. The virus has to be introduced into the plant through a wound. Once inside the cells, it takes over the cellular machinery and uses the cell as a "Xerox machine" to make copies of the virus' nucleic acid and protein. The nucleic acid of the virus contains the blueprint or template for the plant to make more copies of the virus. Most viruses are vectored by insects - that is, they are spread around from one plant to another by insects such as aphids or leafhoppers. The insect picks up the virus on its mouthparts when it feeds on an infected plant, and then inoculates a healthy plant with the virus particles. These insects will not feed on dead plant parts. Some viruses are vectored by nematodes but nematodes would not feed on dead roots. Thus, most viruses survive in insects or in other living plant hosts, such as weeds and other infected plants near the crop. A few viruses can be transmitted by mechanically rubbing a healthy plant with an infected plant, by grafting, by infected seeds, or by vegetatively propagating plants. But most viruses are not transmissible from decayed infected plant debris that may be present in compost. A few economically important viruses are vectored by soilborne fungi, which could survive a long period of time in the soil as resting spores. In summary, with a few exceptions most viruses found in decayed, dead plant material could not infect plants.

Nematodes

The last group of pathogens are microscopic worm-like invertebrates called nematodes. Most infect the roots of plants, feeding on the plant cells. They can feed on the outside of the root or can penetrate the root. Some can infect bulbs, leaves and stems. They have a sharp hollow mouthpart called a stylet that penetrates the plant cells and is used to suck out the cell contents. Nematodes reproduce by laying eggs and usually go through four larval stages before reaching the adult stage. They can survive both as larvae and as eggs. In some nematodes, the larval stage can become dehydrated and survive for a long time in suspended animation. Some nematodes can excrete a protective covering called a cyst around their egg masses. These are very resistant to decay in the soil. In summary, nematodes can also survive in infected plant parts as eggs or larvae.

The potential of plant pathogens to spread or disseminate from CSSSW

To cause disease, all pathogens have to come in contact with the host. But with a few exceptions (and only for a short distance), pathogens cannot move on their own. Unlike insects, this movement is mostly passive - that is, carried out by other forces such as wind or man, much like the seeds of higher plants. Many foliar fungal pathogens can be disseminated by spores floating in the wind or wind-blown rain. Bacteria, which are sensitive to drying, are also spread by rain splash. Insects can also spread fungi, bacteria, or viruses. But one of the primary movers of pathogens has been man. Cultivation practices such as plowing or irrigation, are major ways that soilborne pathogens are spread.

Pathogens can also be spread through movement of infected plant parts, such as seeds, tubers, transplants, bulbs, and infected plant debris. This last method of dissemination will be a primary focus for this report.

From a quarantine perspective, man has been responsible for many of the most destructive plant disease epidemics, by moving a pathogen into a new area where the native or cultivated plants have never had a chance to co-evolve any form of resistance to the pathogen. Thus, all the plants are uniformly susceptible and are destroyed. Notable examples are the Irish Potato Famine of the 1840s, caused by a fungal pathogen introduced into Europe from Mexico; the Dutch elm disease, caused by a fungal pathogen from Europe that has destroyed most American elms in the eastern part of the continent; and chestnut blight, also introduced from Europe, which has destroyed the native chestnuts of eastern North

America.

Can the composting process kill or eradicate plant pathogens from the final CSSSW product?

Based on the evidence cited in the previous paragraphs, one can assume that there is a high potential that urban, municipal, and agricultural plant wastes will contain plant pathogens. The next question that needs to be asked is: Can the process of composting destroy the plant pathogens? Composting involves a heating phase, when thermophilic bacteria produce heat from respiration and breakdown of the organic matter. Thus, the heat generated could potentially eradicate or kill pathogens in the compost. At the same time, there is also a biological aspect to consider - can the microorganisms in the compost pile weaken or destroy propagules of plant pathogens? To answer these questions, we can look at the literature on the survival of plant pathogens in compost. But this literature is very limited. It may be helpful to first look at other literature in plant pathology dealing with the effect of heat on plant pathogens. These are:

1) the use of heat, steam or hot water to eradicate pathogens from seeds, bulbs or soil.

2) the recent use of soil solarization as a means of disinfesting soil in warm climates.

But we emphasize here that it may be difficult to exactly predict the behaviour of pathogens in compost based on this literature. The use of heat or steam involves higher temperatures and shorter periods of time than may be encountered in compost, and there are no biological factors to interact with. The use of soil solarization may involve lower temperatures and longer periods of time than composting. There is a gradient of temperature in the soil, so that the lower layers of soil may not experience lethal heating, allowing the pathogen to recolonize the upper layers after solarization. Thus, there are many complicating factors that may make it difficult to extrapolate this literature to composting. Nevertheless, this literature can provide a good basis to make decisions on the potential risk of pathogens in composting in the absence of more specific studies.

The use of heat to eradicate or destroy plant pathogens

The use of heat to destroy microorganisms has been recognized for over 100 years first in human and animal pathology. Around the turn of the century, the use of steam sterilization in greenhouse and nurseries began as a means of sterilizing soil to eradicate plant pathogens, insects, and weeds. Pathologists found that lower temperatures provided by hot water could be used to eradicate pathogens from plant tissues such as seeds and bulbs, while maintaining the viability of the plant.

The general rule of thumb, based on 50 years of research in this area, is that 65°C of moist heat for 30 min will destroy most important plant pathogens. For example, *Rhizoctonia,* a pathogenic fungus, is eradicated from living tissue by hot water treatment at 50°C for 30 min. Water molds, such as *Pythium ultimum* are even more sensitive, and are killed in plant tissue at 46°C for 40 min, while *Botrytis* is eliminated from plants at 54°C for 15 min. Pathogenic bacteria do not form heat resistant spores, are more sensitive than fungi, and are killed at 60°C-70°C for 10 min. Nematodes are also sensitive to heat. The resistant cyst forming nematodes are killed at 50°C for 15 min, and the root knot nematode can be killed at 50°C for 10 min in living tissues. Most plant pathogenic viruses are killed at 70°C, with a few exceptions. However, soilborne organisms in soil may be more heat resistant than in plant tissues. The use of aerated steam at 60°C for 30 min is now standard practice in the greenhouse industry to treat soils. A few other important things were learned from this research. i) Lethality is a function of both temperature and length of exposure. ii) The moisture level was also an important factor because of the physical properties of heat conduction and heat carrying capacity. Also the moisture content of the microorganism affects its ability to survive heat and moist heat was more lethal than dry heat.

The most recent work on lethal temperatures used against soil fungi in plant tissues was done by Bollen, 1985. He used 30 min exposures and found that the resting spores of fungi such as *Plasmodiophora brassicae* were destroyed at 55°C-60°C, while the dormant spores of *Olpidium brassicae* were destroyed at 60°C. Oomycetes such as *Pythium* and *Phytophthora* were more sensitive to heat, with lethal temperatures of 42°C-50°C. Lethal temperatures for *Fusarium* spp., a common soil borne fungus, ranged from 55°C-65°C.

The use of soil solarization to eradicate plant pathogens

The process of soil solarization, first developed in Israel in 1976, involves the use of clear plastic films or mulches, which trap solar energy and heat the upper layers of the soil. Temperatures of 42°C-55°C are common in the upper 5 cm of soil under a plastic tarp, while the temperature at lower depths may only be 32°C-36°C. Soil solarization studies have shown that the ED_{90}, (the dose at which 90% of the propagules are killed), are related to the temperature and the exposure time, which are inversely related. Soil moisture is also important, as solarization is not effective in dry soils. This relationship between temperature and time was found to be logarithmic. For example, the time needed to reach ED_{90} of *Verticillium dahliae,* a fungus that causes a wilt disease, was 14 hrs at 37°C, but 9 min at 50°C. Similar successes of soil solarization with bacteria have been noted. *Streptomyces scabies,* an actinomycete that causes scab and *Agrobacterium* have been controlled or reduced by solarization. Plant pathogenic nematodes such as *Globodera, Heterodera,* and *Meloidogyne* have also been controlled by soil solarization. Many soilborne pathogens, nematodes and pests have been controlled by 4-8 weeks of solarization. Most plant pathogens are considered mesophiles, and would be killed at similar times and temperatures reported in this review. Table 1 lists some of the pathogens that have been controlled by solarization, while Table 2 lists pathogens that have been partially controlled or not controlled.

Composting and phytopathogens

Organic materials may come from several sources for the purpose of large-scale composting. This allows phytopathogens of diverse origins to be introduced into the compost. Wastes from home gardens can include diseased plants or plant parts. Garbage from food stores and processing plants, containing spoiled fruits and vegetables, is likely to include plant material affected by certain pathogens. When agricultural crop wastes provide a major component of a compost, we have to assume that this compost will contain pathogen propagules, some of them potentially resistant to adverse conditions. Most often they are fungal pathogens, although bacteria,

Table 1. A List of Plant Pathogens Controlled by Soil Solarization (From Davis, 1991).

FUNGI	BACTERIA
	Agrobacterium tumefaciens
Phytophthora cinnamomi	*Streptomyces scabies*
Plasmodiophora brassicae	
Pythium ultimum	**NEMATODES**
Pyrenochaeta lycopersici	
P. terrestris	*Criconomella xenoplax*
Didymella lycopersici	*Ditylenchus dipsaci*
Verticillium dahliae	*Globodera rostochiensis*
V. albo-atrum	*Helicotylenchus digonicus*
Fusarium oxysporum fsp. vasinfectum	*Heterodera schachtii*
F. o. fsp. fragariae	*Meloidogyne javanica*
F. o. f sp. lycopersici	*M. hapla*
F. o. f sp. conglutinans	*M incognita*
Thielaviopsis basicola	*Paratrichodorus porosus*
Sclerotium oryzae	*Paratylenchus hamatus*
S. rolfsii	*P. penetrans*
S. cepivorum	*P. thorne*
Rhizoctonia solani	*P. vulnus*
Sclerotinia minor	*Tylenchulus semipenetrans*
Bipolaris sorokiniana	
Xiphinenia spp.	

Table 2. A List of Plant Pathogens Not Controlled or Partially Controlled by Soil Solarization (From Davis, 1991).

FUNGI
Fusarium oxysporum f. sp. opini
Macrophoniina phaseolina
Plasmodiophora brassicae
NEMATODES
Meloidogyne incognita
Paratylenchus neoamblycephalus

viruses or nematodes may be present. The conditions that prevail in the piles during the composting process can contribute to the inactivation of pathogen propagules in three ways.

1) **Direct effects - heat**. The heat of the thermophilic phase will have a major impact on microorganisms present in the compost pile. Temperatures of 55°C-65°C for a minimum of 30 min may be required to kill the most resistant structures. Sublethal heating also weakens the propagule, so even if it survives, the germination is delayed and its virulence can be reduced. However, preconditioning with high moisture exposure can lower the required temperature for eradication of fungal propagules. It is believed that the high temperature breaks down the fluidity of membranes, resulting in membrane instability and death of the cell. High temperatures also denature and break down enzymes involved in respiration and other crucial biochemical functions of the organism. However, living cells can adapt to heat and acquire thermostability or thermotolerance by the release of heat shock proteins. These are produced very quickly in a cell after exposure to heat, and may help the organism withstand the high temperature. They are short lived in fungi, and it is not known whether they function in heat tolerance.

2) **Indirect effects - biological factors.** Antagonists will also influence the survival of pathogens, especially in the last phase of the compost cycle. Microbial antagonists can contribute to weakening of the propagules and lowering of the required killing temperature. Soilborne propagules of fungi subjected to sublethal heat effects have an increased sensitivity to antagonistic fungi and bacteria that are more thermotolerant. This could make the pathogens more vulnerable to attack from other microbes, through antibiosis, parasitism, or competition. This effect has been seen in solarization, where the pathogen is also more sensitive to fungicides or biocontrol agents such as *Trichoderma.* This may explain why some pathogens are killed with solarization, even at marginal temperatures. This same effect may also function in composts - if the pile is recolonized by antagonistic mesophiles, they could further reduce the populations of the plant pathogens.

2) **Indirect effects** - toxic substances in the compost pile. The production of toxins occurs during the microbial breakdown of organic matter, particularly in the early stages. These include organic acids, phenolic compounds, tannins, ammonia, and other volatiles or sulfur-containing compounds resulting from the decomposition of the plant tissue. These may weaken or kill the propagules, or may act synergistically with heat to kill the pathogen. Although higher levels of toxicity have been related to anaerobic conditions, it is the unstable nature of the substrate in young compost that contributes to toxin metabolism. Despite its potential for destruction of pathogens, the production of microbial toxins should not be encouraged, since problems of phytotoxicity may be later encountered when the finished compost is used in the field.

Other aspects of composting influencing pathogen survival

Since heat plays a major role in pathogen destruction, we must examine every aspect that will affect temperature distribution throughout the materials being composted. The choice between aerated static piles and periodically turned piles will affect the temperature profile of the compost piles. Periodic turning of the piles is not considered to be the most satisfactory approach for disease control. On the other hand, the static piles allow a certain regulation of temperatures through the control of ventilation within the piles. In order to obtain totally successful eradication of pathogens within the compost, the temperature should be as uniform as possible throughout a pile. In some cases, the cooler outer layers of a finished compost pile will not have reached adequate temperatures and pathogens may survive in those areas. Therefore the position of disease-infested plant material in a pile will influence the chances of survival for the pathogens involved.

Plant pathogens in composted materials
Research on the fate of phytopathogens in composted materials appears to have attracted limited attention so far. The approach adopted in previous work done was either testing a pathogen from each major group, that is, fungus, bacteria, virus and nematodes, or concentrating mainly on fungal pathogens. Table 3 lists the pathogens studied in the compost "milieu" and the temperatures they were subjected to while in the composting process.

1) **Pathogens**. Based on the information gathered, nematodes and bacteria are considered to be the least likely to survive the composting process due to their low tolerance of high temperatures. Viruses can withstand high temperatures and those tested have survived composting temperatures. However, the viruses that do survive in the compost might not pose a threat to crops because of their vectors' habit of feeding only on live plants. Fungal pathogens include some species with highly resistant survival structures such as sclerotia, chlamydospores or resting spores. Special attention has been given to *Olpidiunn brassicae* and *Plasmodiophora brassicae,* both of which produce highly resistant resting spores; and to *Fusarium oxysporum* Esp. *melonis* which survives with chlamydospores. Of these three, only *O. brassicae* showed some survival ability in the conditions imposed. However, other forma specials of *F. oxysporum* were not totally eliminated in the same series of tests.

2) **Temperatures**. When referring to the literature on compost and pathogen testing, it is particularly pertinent to relate the results to the methods employed. Workers targeted their studies on the central area of a small compost pile, or looked at either unspecified locations, or at a limited number of locations in a small pile. In many cases, the temperature range reported is wide enough that it would be difficult to decide what temperature is necessary to inactivate the pathogen. The ultimate test could be one where nearly all of the plant material to be composted contained diseased material. Such an experiment was conducted with a tomato pathogen *(Didymella lycopersici)* but the conditions of the experiments were not very uniform, making it difficult to reach a meaningful conclusion. Overall, we know the temperature range which is most likely to result in lethal effects on pathogens. However, due to the potential influence of other factors discussed previously, it is not possible to specify a precise temperature requirement. A relationship exists between exposure time and temperature, such that within certain limits, time will compensate for a lower than optimum temperature in causing thermal death.

Table 3. The Survival of Plant Pathogens in Compost Piles - Summary of Literature.

Pathogen	Composted Host	Temp. (°C)	Survival (+/-)	Reference
Armillaria mellea	not specified	50+	-	Yuen and Raabe (1979)
Botrytis aclada	onion	64-70	-	Bollen *et al.* (1989)
B. cinerea	geranium	40-60	-	Hoitink et al. (1976)
	bean leaves	35	-	Lopez-Real and Foster (1985)
Colletotrichum coccodes	tomato and eggplant	64-70	-	Bollen *et al.* (1989)
Didymella lycopersici	tomato	45-55	+	Phillips (1959)
		39.2-72.8	+	
Erwinia carotovora var. chrysanthemi	*chrysanthemum*	*40-60*	-	Hoitink *et al.* (1976)
Fusarium oxysporum fsp. callistephi	chinese aster	47-65	-	Bollen *et al.* (1989)
F. oxysporum fsp. lilii	lily bulbs	16-51	+	Bollen *et al.* (1989)
		58-70	-	
F. oxysporum f sp. melongenae	eggplant	53-65	+	Bollen *et al.* (1989)
F. oxysporum fsp. melonis	melon	56-67	-	Bollen *et al.* (1989)
F. solani f.sp. cucurbitae	zucchini	53-65	-	Bollen *et al.* (1989)
Meloidogyne incognita	yard wastes	55-65	-	Hermann et al. (1994)
Olpidium brassicae	lettuce	56-67	+	Bollen *et al.* (1989)
Phomopsis sclerotioides	gherkin	64-70	-	Bollen *et al.* (1989)
Phytophthora cinnamomi	rhododendron	40-60	-	Hoitink et al. 0976)
Phytophthora cryptogea	chinese aster	64-70	-	Bollen *et al.* (1989)
P. infestans	potato	47-65	-	Bollen *et al.* (1989)
Plasmodiophora brassicae	cabbage	64-70	-	Bollen *et al.* (1989)
		47-65	-	
	cabbage	35	+	Lopez-Real and Foster (1985)
		56.9	-	
		65-75	-	
Pseudomonas phaseolicola	French bean	35	-	Lopez-Real and Foster (1985)
Pyrenochaeta lycopersici	tomato	53-65	-	Bollen *et al.* (1989)
Pythium irregulare	rhododendron	40-60	-	Hoitink *et al.* (1976)
Rhizoctonia solani	potato	64-70	-	Bollen *et al.* (1989)
	sugarbeets	40-60	-	Hoitink *et al.* (1976)
	riot specified	50+	-	Yuen and Raabe (1979)
Sclerotinia sclerotiorum	lettuce	64-70	-	Bollen *et al.* (1989)
	yard wastes	55-65	-	Herrmann *et al.* (1994)
Sclerotium cepivorum	onion	64-70	-	Bollen et al. (1989)
S. rolfsii	not specified	50+	-	Yuen and Raabe (1979)
Stromatinia gladioli	gladiolus	64-70	-	Bollen *et al.* (1989)
Verticillium dahliae	not specified	50+	-	Yuen and Raabe (1979)
Tobacco mosaic virus	yard wastes	55-65	+	Herrmann *et al.* (1994)
Tobacco necrosis virus	French bean	35	+	Lopez-Real and Foster (1985)
		56.9	+	
		65-75	-	

Recommendations for future research, policy and regulation of CSSSW

Based on the literature review, one can assume that the plant material going into CSSSW could contain plant pathogens. This could be from yard or garden wastes, agricultural wastes, or lawn or golf courses wastes. The pathogens may be present in the sawdust, bark or straw used as a bulking agent, or in manure. Other pests, such as weeds and insects, may also be present in the plant material, and many of these concerns would also apply to these pests. If the source of materials was from one type of crop waste, then one could make assumptions about the potential pathogens that may be present, since each plant is attacked by a limited number of pathogens. But given the multiple sources of material for composting, this is not possible. One has to assume that any pathogen present in the geographical area where the wastes are collected could be in the compost.

Future research needs

We obviously do not have the scientific data at present to completely answer the questions about whether a given pathogen can survive in compost. Given the potential risk of infesting agricultural lands and the economic costs of controlling those diseases, we need a higher degree of certainty than just basing our decisions on a limited amount of data and literature.

The following is a discussion of research needed to make scientifically sound decisions on policy, use, and regulation of CSSSW.

1) Prioritize the pathogens to be tested. The first step would be to prioritize the pathogens to be investigated. There are over 13,000 fungi found on plants and plant products in the United States alone. It would be impossible to test all of these. Instead, a list should be made, in consultation with plant pathologists. Soilborne pathogens that form thick-walled survival structures would be high on the list as they would have the potential to survive the composting process. The potential of the pathogen to inflict economic damage on a crop could be drawn from host-pathogen records and indices for Canada and the United States, such as: Farr *et al.* 1989. (Fungi on Plants and Plant Products in the United States, APS Press, St. Paul, Minn.), Names of Plant Diseases in Canada. 1992. (Société de protection des plantes du Québec), Conners, 1967. (An Annotated Index of Plant Diseases in Canada Agriculture Canada), Martens *et al.* 1984. Diseases of Field Crops in Canada (Canadian Phytopathological Society), Howard *et al.* 1994. (Diseases and Pests of Vegetable Crops in Canada, Canadian Phytopathological Society).

Much of this information is also becoming available and updated on the Internet system. This decision on the importance of the pathogen would also have to take into account the epidemic potential of the pathogen and whether it is a monocyclic or polycyclic disease. Most soilborne pathogens are monocyclic - that is, they produce one disease cycle per season and reproduce once during the summer. Once established, they are slow to spread in the field, unless inadvertently helped by man via cultivation. However, some diseases are polycyclic, and produce many cycles of reproduction and infection throughout one season - some can complete their life cycle in 7-10 days! These are mostly foliar diseases and have a high epidemic potential, provided that the environment is favourable and the plants are susceptible. This potential is independent of the amount of initial inoculum introduced into the field. Because of the logarithmic or exponential nature of the development of these diseases, a small amount of inoculum can be multiplied in a very short time. These pathogens should have a lower threshold of inoculum needed to cause disease. Therefore, we need a greater certainty that these pathogens are not present in the finished compost. The priority should be on diseases that normally originate from crop debris present in the field, such as foliar blights that overwinter in pycnidia, a type of fruiting body. On the other hand, if a polycyclic pathogen originates from inoculum a long distance away and is spread by wind, such as many rusts and powdery mildews, then eliminating sources of infection from compost in the field is a moot point.

The potential of the pathogen to persist in the soil for a long period in the absence of the host relates to the difficulty of controlling the pathogen. Some pathogens, such as the fungus that causes club root of crucifers, can persist in soil for many years, even in the absence of susceptible crucifers. Crop rotation as a means of control would not work. Another example is vascular wilt pathogens, such as forma speciales of *Fusarium oxysporum.* They can persist in the soil for many years and there is no economic way of eradicating or controlling them, short of using resistant cultivars (which are not available for all crops). Also, these pathogens can become systemic and are devastating, because one successful infection event is enough to kill or stunt the plant, unlike other diseases which have localized infections. The difficulty of disease control, should the pathogen be introduced, must be considered. Also, the presence or absence of a pathogen in a given geographical area is important. If the pathogen is not present in an area, based on current disease surveys, then the pathogen would have a low priority for study in compost.

2) Test of heat resistance and survival of pathogens in the laboratory and compost piles. Once the pathogens are prioritized for their possible impact on the compost product, the next step will be to perform relevant experiments under conditions as close as possible to the reality of a compost pile. The initial screening of heat resistance could be done in the laboratory, provided the appropriate techniques were used.

These appropriate techniques include the use of biologically-relevant inoculum. Many studies in the past have used inoculum grown in sterile Petri dishes on agar or liquid medium. The structures formed on sterile nutrient-rich media may not be physiologically the same as those formed in plant debris. Laboratory-grown inoculum may over or under estimate the ability of the pathogen to survive heat. For example, inoculum formed under nutrient-rich conditions in the laboratory may be more able to survive than inoculum formed under nutrient-stressed conditions in the field. Inoculum formed in the field may also have other microbes or fauna that have attacked and weakened it. Thus, inoculum in plant debris may be killed at lower temperatures. On the other hand, inoculum formed in plant debris may be better protected against heat than laboratory-raised inoculum. We therefore recommend that inoculum be grown in the laboratory on the appropriate plant debris, not on petri plates or liquid media. For obligate parasites, of course, this is not a relevant question, since they can only be propagated on living plants.

Also these techniques should include the use of temperatures, durations, and periodicities in the laboratory relevant to composting.

Most of the past research on heat resistance and lethal temperatures has been done with high temperatures for short exposures (30 min). Devices are probably on the market that are controlled with microprocessors and can be programmed to mimic a compost pile - a slow rise in temperature over a few days, a period of maintaining the high heat, and then the cool-down period. This could also be done a number of times, to imitate the numerous turnings and heating periods of the compost pile. This type of device may be available in the material testing and engineering fields, although we have not seen its application in plant pathology.

Other techniques include testing the survival of pathogens in replicated compost piles. The laboratory testing with temperature alone leaves out the possible biological and toxicological factors that may be present in a compost pile. These should be tested, using the techniques developed for the MSc project of Monique Paré. Briefly, this involves the placement of sachets of inoculum in the replicated compost piles at set locations. These sachets are removed during turning and returned to the same place. In addition, other sachets with inoculum are spread randomly throughout the pile and remain during turning. At the end of the experiment, the sachets are removed and the samples are analysed for the viability of the pathogen. In addition, temperature is monitored in the pile throughout the experiment and leachates are analysed.

3) Development of new techniques for detection of viable pathogens in compost: Testing the survival of pathogens in compost piles is extremely labour intensive and there are some inherent problems with the detection techniques. More research is needed to develop cheaper, more reliable and more sensitive methods. A brief summary of the techniques will point out the advantages and disadvantages of each.

In plating techniques, inoculum is placed on an agar medium in a Petri plate, with or without selective agents, in hopes that the fungus or bacteria will grow into the agar, so it can be isolated and identified in culture. This works fine for diseased plant tissue, before decay has set in. Once other secondary and saprophytic organisms colonize the material in succession, it becomes more difficult to isolate the pathogen, which may be slower growing and less competitive than the secondary organisms. Sometimes chemicals are added to the media to kill the saprophytes and give the pathogen an advantage, but this only works if a selective agent can be found that does not also inhibit the pathogen. Thus, not all pathogens may be recoverable from compost using this technique.

In serial dilution and plating the sample is ground up in sterile water and the slurry is diluted and plated on agar media. The assumption is that the pathogen propagules are still numerous, and can be diluted away, or separated from the other contaminating organisms. But if the saprophytes outnumber the pathogen, this technique does not work. These techniques also do not work for propagules that have an endogenous dormancy. Many times, these dormant spores will only germinate when stimulated by exudates from living plants. However, these culturing techniques are cheaper and faster than bioassays.

Bioassays are probably the most accurate and sensitive techniques, but very costly and time consuming. Greenhouses or growth chambers are needed and the plants must be maintained for a period of time. In this technique, the inoculum is mixed into pasteurized greenhouse soil and a susceptible host is planted. Assuming the plant is susceptible and the environmental conditions are right, the plant should develop the symptoms of the disease. This is useful for pathogens that may not be culturable, such as obligate parasites, or for dormant propagules. However, the efficiency of the inoculum may be low, so if there is not enough inoculum, the disease may not develop, although the pathogen is present. This could be overcome by multiple plantings into the same pot - that is, pull up the crop and replant it, to enrich and build up the population of the pathogen to the paint that it will cause disease symptoms. Bioassays are probably more sensitive and get around the problem of secondary colonizers interfering with the isolation of the pathogen. However, if environmental conditions are not optimum, one may get a false negative reading.

With vital staining the viability of fungal propagules can also be determined indirectly by vital stains. If the propagule can be seen in the plant tissue, or extracted from the tissue, the spores can be stained and examined microscopically. Vital stains are taken up by living cells, and change a characteristic color if metabolic processes are occurring in the spore - that is, the spore is respiring. For example, tetrazolium salts are changed in color if they undergo oxidation-reduction by respiratory enzymes in the spore. If esterases are present in the cell, they will cleave fluorescein diacetate (FDA) to form a compound that fluoresces brightly under UV microscopy. This method can detect whether the fungus is alive, without having to grow it or infect a plant. This would be ideal for detecting dormant propagules or obligate parasites, both of which would be difficult to culture. However, unless the spores have a unique shape or morphology, it would be difficult to visualize them among other fungi colonizing the tissue. This method could not be used with bacteria, nematodes, or viruses.

For all of the above, research is needed to determine the threshold level of detection (sensitivity) of the method - what is the lowest population that these methods can detect? Also we need to determine the probability of an error in saying that the pathogen is not there, when it really is (false negative). The efficiency of all these techniques will have to be tested with spiking experiments - that is, adding a known amount of the pathogen to a sample, and seeing how much of it you can detect with the given method.

Recent developments in molecular biology and biotechnology have given us new tools that may be used to solve the problems outlined above. The problem of determining whether a pathogen is present has been addressed by plant pathologists trying to diagnose plant diseases by detection of the causal agent in plant tissue. Two new technologies could be applied to the detection of pathogens in compost: **ELISA** (Enzyme-Linked Immunosorbant Assay) and **DNA** techniques.

ELISA techniques are based on the specific antigen-antibody reactions. Antibodies (usually polyclonal) are produced in animals injected with the purified pathogen - fungus, bacteria, or virus. Specific antibodies to the antigen are extracted from the blood of the animal and purified. These antibodies are conjugated with enzymes that change a colorless substrate into a colored one. The sample and antibody are placed in small plastic wells. If the antigen is present and sticks to the antibody, the enzyme attached to the end of the antibody will change the reagent to a color, which can be recognized as a positive reaction. These methods have been used extensively in plant pathology and medicine for almost 20 years to identify fungi, bacteria and viruses. The problem with compost would be getting a purified sample free of the colored contaminants that may interfere with the reaction. The use of mini-columns to purify the protein (antigen) from the compost sample may provide a way to do this. ELISA kits are commercially available for some soilborne pathogens.

Until the development of PCR (polymerase chain reaction) a few years ago, **DNA technique** did not hold much hope for this application. The basis of this technique is that every organism has a unique sequence of DNA, a linear molecule made of repeating base subunits, which carries the genetic "blueprint" of the organism. If you developed a probe (a piece of DNA with the sequence of the organism you were looking for), you could mix it with a sample of DNA from the unknown organisms. If the sequences matched up (hybridized), this could be detected and would prove that the unknown organism was similar or identical to the probe. However, the amounts of DNA needed for this method are large, and it would be difficult to isolate the required amount of intact DNA from a compost sample. Also, phenolics and other humic compounds in the compost would interfere with the isolation of DNA. With the PCR technique, small amounts of DNA can be amplified or increased to the level that they can be hybridized. This technique uses a primer specific to the organism one is looking for, or can use small random primers available commercially - RAPD - Random Amplified Polymorphic DNA. This primer, a small piece of DNA binds to the unknown sample, and an enzyme makes a copy of that piece of DNA. The two strands are broken apart, and the copying processing goes on for a number of cycles, usually overnight. In essence, if a small bit of DNA from the pathogen is there, this method multiplies it enough to be detected. This method is very sensitive - theoretically, only a few cells worth of DNA is needed. However, there is the problem of isolating intact DNA that is not broken down.

For both ELISA and DNA techniques, there is a large development cost involved to come up with the antibodies or primers/probes needed for each organism. In addition, the DNA methods may be too specific. They will only recognize certain strains or genotypes of a species. On the other hand, ELISA techniques with polyclonal antibodies are more robust, and can be species or even genus-specific.

Another problem may be false positives. At 68°C-70°C, most DNA is degraded and denatured, and would not be detected. However, it may still be intact in killed cells at lower temperatures. So you may detect intact strands, even though the organism is dead. The same is true for ELISA techniques. In many cases, the protein may be detected, even though it has lost its tertiary and secondary structure needed for enzyme activity. As long as the primary structure, or sequence of amino acids, is preserved, it could be detected, even though the organism was killed. On the other hand, once cells are killed, the proteins and DNA may be broken up by proteases and DNAases produced by other organisms in the compost. Finally, there is still the problem of extracting a pure enough sample to be used with these techniques. Numerous compounds in the compost may interfere with the sensitive chemical reactions that these techniques are based on.

Development of statistically sound sampling techniques is required. After a good method of detection is developed, there are still other questions about sampling. Consultation with a statistician would provide a sound sampling technique, based on the distribution of the pathogen in the pile, the population, and the statistical variance. This research could answer the following questions: when to sample (probably based more on the maturity of the compost), where to sample (location in the pile), the size of the sample, the number of samples needed to make a statistically sound decision on the presence or absence of the pathogen.

Policy and regulation issues

Several issues need to be considered:

1) Quality control. Assuming that the testing shows pathogens can be killed in a proper composting process, a quality control program would have to be developed. This would include monitoring of temperature to assure that the pile was properly heated to the temperatures needed to kill pathogens. This could be done with thermocouples and data logging devices. However, since the temperature varies depending on the location in the pile, other techniques would have to be used to assure that all the pile was exposed to the lethal temperatures. This could be done with temperature-sensitive tapes enclosed in metal disks, which could be randomly placed in the pile at the start, and recovered at the end using a magnet. The tapes could be retrieved and read, to determine the maximum temperature that the disk was exposed to.

Also testing of the finished compost for phytotoxicity and presence of pathogens is an important quality control issue. Again, one could focus on testing for pathogens that may be harmful to the crop on which the CSSSW is used, using the criteria outlined above. This could be a combination of plating, vital stains, bioassays, ELISA, or DNA techniques.

2) Risk assessment or cost/benefit analysis. There is also a question of stringency of regulations - should the same standards be applied to all pathogens? Will the cost of regulation and quality assurance be greater than the value of the product? Should all pathogens have a zero tolerance? These questions cannot be answered the same way for every crop and agricultural system. An analysis should be done on each potential crop that the CSSSW would be used on. Several points could be explored.

What if the pathogen is already present on the land? Many pathogens, such as *Pythium* spp., have a wide distribution, and may already be present in the soil. Their populations would depend on the crop grown and biological and environmental factors, rather than on small amounts potentially introduced in compost.

Could small amounts of some pathogens be tolerated in the compost, if the pathogen is not already present in the soil? This would apply to pathogens that are slow to spread, do not survive in the soil very long, or can be adequately controlled by crop rotation.

Could the compost be applied to fallow land or land with a cover crop, so that if there were low numbers of pathogens present, their populations would decline in the soil in the absence of a host? This may apply to pathogens that cannot reproduce on weeds or the cover crop, or cannot grow on organic matter as a saprophyte. Thus, by planting the next season, the populations will have declined below the economic threshold.

Do applications of compost in horticultural/ nursery/greenhouses require more stringent standards than applications to agronomic land? In the greenhouse, the potential value of the crop is much higher, and if a disease is introduced, there is a greater chance of destruction. Seedlings are more susceptible to many diseases. Because plants are close together in a greenhouse, it is easier for pathogens to be splashed around and spread to neighbouring plants. Greenhouse soils lack the natural microflora that would normally keep pathogens in check. Some pathogens, like *Pythium,* can quickly spread in greenhouse beds.

3) Quarantine considerations. Some economically important pathogens may be confined to a small geographical area, and quarantines are in effect to keep them from spreading to the rest of the country. Agriculture and Agri-Food Canada and Revenue Canada, Customs, Excise and Taxation currently enforce regulations regarding the shipment and movement of plant and plant products across borders and within the country. If an area came under quarantine action, then composted material made in that area should not be used on agricultural lands outside of the quarantine area, given the potential risk of introducing a serious pathogen or pest into new areas. For example, Newfoundland is currently quarantined for the potato wart pathogen, *Synclrytrium endobioticum.* Potatoes are not exported and measures are taken to remove soil from vehicles, to prevent the movement of this pathogen into other potato growing regions of Canada, such as Prince Edward Island and New Brunswick. A similar scenario could arise in the future if an exotic pathogen was accidentally introduced into Canada, and quarantine measures were needed to keep it from spreading to the rest of the country.

ANIMAL PATHOGENS (Spencer, J.L.)

Unwise handling and disposal of municipal and agricultural wastes have no doubt contributed to widespread contamination of lands and waters with pathogens. For example, livestock and poultry raised under intensive management practices have often been shown to be intestinal carriers of *Salmonella* and other pathogens and yet their wastes are freely applied to agricultural land (Hilliger, 1980). *Salmonella* organisms are also present in municipal wastes (Gabby, 1975) and can enter water systems from landfills. Flies, rodents, birds and pets can pick up pathogens, such as *Salmonella,* in the environment and contribute to the spread of infection among food, animals and humans.

Practices that favor spread of pathogens

Pathogens such as *Salmonella* spp. are facultative anaerobes and are not readily killed in landfills. Tiled agricultural land favors spread of pathogens that survive in water drained from the lands. Earthworm activity likely contributes to elimination of *Salmonella* and other pathogens in soil (Murry and Hinckley, 1992; Amaravadi, *et al.*, 1990). Thus, land management practices that reduce earthworms, could contribute to survival of pathogens in organic matter applied to land.

Composting methods

Two methods have been used to compost solid wastes. The first relies on mixing of ingredients to promote microbial growth. The effectiveness of this system in eliminating pathogens is largely dependent on heat production. The second uses earthworms to promote microbial activity. No heat is produced and enzymatic activity appears to be responsible for killing of certain pathogens.

1) Composting to generate heat. Threshold temperatures for killing of pathogens in compost range from 60°C-70°C and it is usually recommended that these temperatures be maintained for 3 or more days (Wiley and Westerberg, 1969). In addition to heat, factors such as gas production (ammonia), competition among bacterial spp. and antibiotic activity contribute to elimination of pathogens during the composting process. Carbon/nitrogen ratio, moisture and aeration must be carefully regulated to ensure destruction of pathogens. For example, certain pathogens will survive in parts of a compost pile that do not have adequate moisture.

Gabby (1975) reported that *Salmonella* and *Shigella* in refuse were killed by composting. In the same study a variety of pathogens was inserted into piles and were also killed during the composting process. *Leptospira* and a number of genera of molds were readily killed. Human parasitic cysts and ova disintegrated after 7 days. A strain *of Mycobacterium tuberculosis* was destroyed within two weeks. Parasitic ova from dogs did not disintegrate but no tests were conducted to establish viability. Wiley and Westerberg (1969) inserted *Salmonella newport,* polio virus type 1, *Ascaris lumbricoides,* and *C. albicans* into piles and reported they were killed during composting.

2) Composting with earthworms (vermicompost). The earthworm *Eisenia foetida* has been used in composting municipal refuse. While earthworms promote microbial activity, they also feed on micro-organisms. *Eisenia foetida* was shown to have virucidal activity against certain plant viruses (Amaravadi *et al.*, 1990). Flack and Hartenstein (1984) showed that earthworms could grow by feeding on human bacterial pathogens as well as on non-pathogens. Murry and Hinckley (1992) found that earthworms promoted microbial activity that was antagonistic to *Salmonella enteritidis.* Recently Spencer and Garcia (1995) have shown that vermicompost can be used in the control of *Salmonella* in chickens and turkeys. Resistance of chicks to intestinal colonization by *Salmonella enteritidis* and *Salmonella typhimurium* was greatly increased if they were fed a small quantity of vermicompost produced by earthworms fed chicken feces.

Composting strategies

There are various composting strategies which will impact on animal pathogens.

1) Combining of wastes. Combining refuse and sewage sludge has been found effective for obtaining the optimum carbon/nitrogen for effective composting. Consideration should also be given to combining agricultural wastes (manure, old hay) with municipal refuse.

2) Mixing vs layering of wastes. While the usual practice is to mix wastes together, layering of wastes has proven useful for composting dead poultry. The layers consist of old hay, litter containing manure, and dead birds. Sufficient heat is generated to

kill most pathogens before piles are disturbed. When the piles are moved and secondary piles are created there is further generation of heat which completes the composting and sanitizing process. Layers consisting of hay, refuse, sludge or animal manure may work well together in primary piles. With this system piles could be built up over a period of days.

Concerns for composting practices

There are some concerns regarding composting practices that will have an important effect on animal pathogens.

1) Composting systems that generate heat. Ontario guidelines (Ahlberg, 1991) suggest that in windrow and static pile composting, the pile temperature must be maintained at 55°C-60°C for at least 15 consecutive days to inactivate pathogens. Windrows must be turned over at least 5 times. Static piles must also meet the above temperature requirements. In practice it is unlikely that the temperature throughout the pile would be maintained above 55°C for 15 days. Another concern is that compost could be re-contaminated if turned or handled with contaminated equipment. In the case of static piles, material at the base of the pile may not be adequately composted. When piles are covered with insulating material, this material could become contaminated and preserve pathogens.

Ontario guidelines indicate that a temperature of 55°C-60°C maintained for 3 days during In-vessel (mechanically mixed and aerated) composting should be sufficient for killing pathogens. The system must be engineered to ensure that the sanitized product is not re-contaminated.

2) Vermicompost. Vermicompost systems are being promoted for managing of municipal wastes. Some of these operations are large and the product will be applied in greenhouses and on land. Little attention has been given to survival of pathogens.

Research needs

A brief survey of research needs associated with animal pathogens related to CSSSW follows:

1) Need for predictive modelling and risk analysis. Models and modelling efforts are required to predict types and levels of pathogens likely to be in source-separated solid wastes and in other materials added to promote composting. Microbiological assay systems to predict killing of pathogens and indicate thoroughness of composting are required to support this modelling effort. Also the application of Geographic Information Systems (GIS) to match compost to land in order to minimize health risks (associated with pathogens, metals and potentially toxic materials) and to maximize crop yields from the land (Dr. A. Kobylecki, personal communication) are required.

2) Survival of pathogens. We need to identify mechanical factors that influence the efficacy of composting systems (heat generating) in killing of pathogens, determine if microbial preparations added to promote decomposition have an influence on survival of pathogens, and study survival of animal pathogens in vermicomposting systems.

AGRONOMIC CONSIDERATIONS

(Simard, R.R.)

Composts, to be acceptable for agricultural use, must be devoid of pathogens, have desirable physical properties and must be sufficiently mature (Mustin, 1987). To achieve that, organic residues must be conditioned by an efficient composting process (Garcia *et al.*, 1992; Van der Werf, 1993). These residues will have to be sorted, crushed and sieved prior to be submitted to a aerobic thermophilic fermentation process. In this process microbes are decomposing the organic matter producing significant amounts of CO_2 and to some extend of N gases which are considered nutrient losses (Parker and Sommers, 1983; Agriculture Canada, 1992; Gautier, 1992). This process will then result in a decrease of the C/N ratio and a concentration of the other nutrients (N'dayegamiye, 1990). Nitrogen will be reorganised in more complex molecules and the concentration of other nutrients will be increased. Thus nitrogen mineralization is a key issue in the agronomic use of composts.

Composts as a nutrient source

Carbon and nitrogen

Compost contains large amounts of C and its addition will result in increased soil C content. A part of this carbon will be used as energy source by microbes resulting in increased microbial activity (Lampkin, 1990; Karlen et al., 1992; Robitaille *et al.*, 1994). The kinetics of decomposition of composts will be effectively monitored through the characterization of organic matter components or attributes such as light fraction or macroorganic (particulate) matter, mineralizable C and N, microbial biomass and soil carbohydrates and enzymes (Gregorich *et al.*, 1994).

The evaluation of the amount of plant-available N equivalent to commercial fertilizer N is the subject of numerous investigations. For example, composted manures have lower mineralization rates than fresh manures (Brinton, 1985; MENVIQ-BIOREX, 1989; Hébert *et al.*, 1991; Hamel et al., 1995). Results of incubation studies suggest that nitrogen mineralization of compost is dependant of numerous factors such as their total N content, their C/N ratio, their degree of maturity, the lability of C, etc. (Castellanos and Pratt, 1981; Aoyama, 1985; Leclerc *et al.*, 1986). Other studies have shown that N mineralization was inversely related to C/N ratio (Sims *et al.*, 1992) or not related at all to this parameter (Hébert, 1989). Other indices such as cellulose/hemicellulose ratio (Lineres, personal communication) or the energy: nitrogen ratio (Jansson and Persson, 1982) can also be of interest to describe the mineralization potential of composts.

In addition to factors related to their composition but to a lesser extent, N availability from composts will be determined by biological and chemical changes following their application to soils (Sims, 1995). Therefore climatic (moisture supply, temperature), soil physical (texture, pore size distribution) and chemical factors (pH, C/N ratio, cation exchange capacity) or cropping practices (crop type, tillage intensity, crop residues, previous fertilizer applications) will also play a role in controlling N availability from compost. For composts with high mineral N content, the total and the mineral NH_4-N contents must be included to estimate accurately the amount of potentially available N *(PAN)* as described in Eq. 1.

$$PAN = km\ (No) + ef\ (NH_4\text{-N})$$

where *km* is the percentage of organic N (No) mineralized and *ef* is a recovery factor for NH_4-N which depends on the method of application and the time between application and incorporation into the soil (CPVQ, 1983; Bitzer and Sims, 1988). The *km* values, derived from laboratory studies were reported to vary from -10 (municipal solid waste-sludge co-compost (Sims, 1990)) to 67% for aerobically digested municipal sewage (Sims, 1995). This *km* value will probably be lower under field conditions. In fact, adding compost may result in net N immobilization for periods of up to 20 weeks (Sims, 1990) which suggest that these materials (C/N ratio >25) can be efficiently used to act as a trap for residual nitrates (Maynard, 1989).

Studies conducted in Eastern Canada have shown that spring applied compost may result in net N immobilization (Hamel *et al.*, 1995; Robitaille et al., 1994) and that composted manure is much more efficient if applied in the previous fall (Hamel *et al.*, 1995). Therefore this immobilization period suggests that models used to describe the kinetics of N release should allow for lag phases followed by increases in mineralization. Several models are available to describe this behaviour (Ellert and Bettany, 1988). Composts with small C/N ratios may also result in nitrate losses (Centre de Recherches en Horticulture Université Laval (CRHUL), 1995) especially if they contain a significant amount of inorganic N that may come from added material such as poultry manure. Thus it will be important to study the dynamics of N release from compost under field conditions to adequately quantify the amount of PAN to crops and to diminish nitrate leaching to surface and groundwaters.

Phosphorus and potassium

The phosphorus content must be taken into account when compost is to be applied to agricultural land. As for other organic amendments, applications rates based on PAN will result in P and K buildup to excessive levels (Chang *et al.*, 1991; Hamel *et al.*, 1995). Also a significant portion of the P in compost may be in organic form which may increase P migration downward the profile and increase the treat of eutrophication of surface waters (Bembarek *et al.,* 1994; CRHUL, 1995). Compost may also have an impact on P and K availability by increasing microbial activity, thereby decreasing the fixation of these, elements in the slowly available forms. The P availability is supposedly equivalent to what is found in manure (MENVIQ-BIOREX, 1989). Application rates based on the P content would require that supplemental N be added to meet plant needs and therefore would probably not be economical. This raises a question on the use of composts on P rich soils. Will it result in greater P migration and thus contribute to the P loads reaching surface waters?

Compost and salt

Composts containing sewage sludge, domestic refuse or biofilters may contain large amounts of salts (CRHUL, 1995) which may restrict their use in salt-affected soils such as found in certain dry areas of the prairies. This may result in disruption of soil aggregates and restrict water infiltration. Germination may also be retarded if the salt content is too high. The salt problem would be of less importance in the more humid areas of the country (Caroll, 1982). Incorporation of the material by primary tillage may also decrease the risk of salt-related problems.

Compost and metals

Industrial and municipal composts may contain large quantities of transition metals and metalloids (Cr, Ni, Cu, Zn, As, Se, Cd, Hg). The disposal of alkaline batteries in house garbage and the presence of plating industries in cities are definite sources. Their total concentration is used for classification purposes (BNQ, 1995) and will dictate the rate of application (MENVIQ-MAPAQ, 1991; USEPA, 1993). Although waste application to meet crop N requirement rarely exceeds annual loading rates, the cumulative loading rate ultimately eliminates a certain percentage of arable land suitable for organic waste application (Sims, 1995). Soluble organics may complex the metals and greatly enhance their bioavailability or their migration potential, in the short term, in soil profiles. However, single applications should not result in contamination of groundwater, subsurface horizons may retain a large portion of these metals (Sawhney *et al.*, 1994). Very few experiments have been conducted on the impact of repeated application of composts on metal bio-availability on acidic soils. The solubility of these metals is orders of magnitude higher under these conditions than in neutral and calcareous soils. This may have a large impact on export crops such as wheat which have stringent regulations on metal (Cd) content such as the European community. Research is needed on the impact of composts on the plant availability and potential mobility of potentially toxic metals.

Impact on plant pests and nutritive value

The use of compost may result in the reduction of certain root diseases. For example, Nelson and Craft (1992) have observed a better suppression than commercial fungicides of the dollar spot *(Slerotina homeocarpa)* on golf greens. Repression of diseases in potato production by the application of organic amendments has also been recently reported (Lazarovits, 1995). Care is needed for immature composts as pathogens might still be present if the thermophilic phase was not completed. The quality of food produced organically is an old controversy. Howard (1947) stated that organic composts additions resulted in crops with a better nutritive value. However, research carried out does not often result in differences among nutrient sources (Brandt and Beeson, 1951). Reports of decreased contents of nitrates in leafy vegetables of lower pesticide contents are numerous in the specialized literature (Lampkin, 1990). There is certainly a lot of consumers for which the image of organically grown produce is much better and healthier than conventionally produced food. A lot of basic research is needed to document the impact of composts on soil and plant health.

Impact on physical properties

By adding a lot of low density organic matter, composts and other organic amendments are stimulating faunal (earthworms, insects) as well as microbial activity (Tomlin *et al.*, 1993; N'dayegamiye, 1990; Larochelle *et al.*, 1993). This larger C content will result in improved physical properties such as decreased bulk density, increased macroporosity, structural stability and hydraulic conductivity (Duval *et al.*, 1993). This in turn will increase the water holding capacity, reduce runoff through better infiltration and reduce the risk of water and soil erosion. Thus adding composts would be particularly attractive to restore the productivity of eroded soils. Monoculture with potatoes or corn has also resulted in very significant organic matter depletion in Eastern Canada which has resulted in structural degradation and loss of porosity and infiltration capacity (Carter, 1993; Tabi *et al.*, 1990). Because of the inherent diversity in compost composition, information is needed on the amounts necessary to restore productivity and on the duration of the beneficial effects of compost additions on physical properties.

Conclusion

This short literature review does not pretend to cover all agronomic aspects of compost use in agriculture. In spite of the important body of literature some questions remain:

1) Nitrogen mineralization dynamics and identification of a suitable index of this property in a given soil and growing condition.

2) Long-term impact of compost additions on the accumulation and bioavailability of less mobile elements (P, metals) and on their potential migration in acidic soils.

3) Amounts of compost needed to restore the physical properties of degraded soils and the duration of this improvement under our climatic conditions.

4) Impact of composts on the functional biodiversity in soils and on plant health.

PART C: RECOMMENDATIONS FOR IMPLEMENTATION AND COORDINATION OF THE NATIONAL AGRICULTURAL COMPOST TRIAL

INTRODUCTION

It became obvious during the workshop that a consensus on a single experimental design to evaluate the impacts of CSSSW application would be impossible to reach. This was due not only to geographical considerations but also to the varied background and perspectives of the participants. Each site study would have to include and respond to, as a first priority, local/regional interests and issues. The intricacy of Canadian agroecosystems and the heterogeneity of feedstocks used to prepare composts creates considerable layers of complexity for the NACT design. It was obvious that the NACT would have to cover not only agronomic aspects but also resolve some of the methodological deficiencies. We could not deny that the current methodology for assessing compost maturity and safety, and the understanding of composting and edapho-pedogenetic processes and phenomena were limited. This is particularly the case during economically viable restoration of degraded cultivated soils.

Composting is not a panacea and compost with a similar quality rating would not necessarily have identical impacts on different agroecosystems. Issues related to organic - inorganic interactions and threshold values for contaminants are particularly important if the NACT is to promote the use of compost on agricultural land.

In response to these diversified interests and perceptions, we are proposing not a single experimental design but rather a conceptual framework which will provide flexibility for all potential regional situations. The framework provides the opportunity to select indicators that are direct or indirect measures of land management practices. We also present an analysis of the land-use situation in Canada in which an example of applying the conceptual framework is outlined.

A series of specific recommendations for the implementation of NACT are also included; study sites, need for standard methodologies, minimum data set, coordination, and funding.

A CONCEPTUAL FRAMEWORK TO ASSESS LAND APPLICATION OF CSSSW

(Acton, D.F. and G.A. Padbury)

A conceptual framework was developed by Acton and Padbury (1994) to provide a structure for organizing our knowledge of the factors that determine the quality of a soil to facilitate the development of procedures for assessing and monitoring soil quality in Canada. The purpose of this chapter is to review this framework, emphasizing the need for considering soil quality within the context of applying composted source-separated solid wastes to agricultural land.

The framework considers soil quality as the capacity of the soil to produce crops in a sustainable manner without impacting negatively on the environment. It recognizes that soil quality is determined to a large part by the inherent properties of the soil but that land-use and management practices, in general, and additions of composted source-separated solid wastes, in particular, may substantially change these inherent properties. Two general approaches to soil quality assessment and monitoring are recognized and integrated into the framework. The framework utilizes research on land-use, soil management, and chemical additions to predict change to soil quality. A capability to assess and monitor soil quality and soil quality change can be developed by linking these predictive capabilities with appropriate databases. Direct measurement of change to critical attributes serves as a means to validate predicted values.

In the presentation to follow, the term evaluation of soil quality implies any consideration of soil quality in time and space. Soil quality assessment, on the other hand, is an evaluation of the capacity of the soil to perform a particular function at a given point in time. Monitoring represents the act of repetitive measurement of this capacity.

Soil quality

Soil functions

Soil quality describes a capacity or capability of the soil to perform certain functions in a sustainable manner. McKeague (personal communication) described soil quality as the degree of excellence of the soil in terms of its capacity for sustainable crop production while preserving a healthy environment. Karlen et al., (1990) described soil quality in terms of the physical, chemical and biological attributes of the soil, including the water that is retained, transmitted through, or runs off the soil. Anderson and Gregorich (1984) considered soil quality to be the sustaining capability of a soil to accept, store and recycle water, nutrients and energy. Larson and Pierce (1991), recognizing the dual importance of environmental sustainability and sustainable crop production, embraced many of these concepts as they considered soil quality to be the capacity of soil to function within the ecosystem boundaries and interact positively with the environment external to that system.

They suggest that the quality of a soil should be considered as a composite of its chemical, physical and biological properties as they perform three critical functions: i) provide a medium for the growth of healthy plants, ii) regulate and partition water flow through the environment, and iii) serve as an effective environmental buffer. The growing concern for climate change and the impact of land management, including soil quality, on this change suggests that gaseous partitioning could be considered as a fourth critical function.

The four critical functions of soils alluded to above reflect the current desire of producers, other resource managers, and the public for environmentally sustainable crop production systems. Accordingly, and for ease of presentation, these four critical functions are placed into two groups, each representing expectations placed on soils by various segments of society:

1) Sustainable crop production - the capacity of the soil to produce crops of high quality, and

2) Environmental sustainability - the capacity of the soil to maintain and protect the integrity of the environment in the immediate and in adjacent ecosystems.

Soil capacity

The determination of the soil's capacity to perform the critical functions mentioned above requires consideration of many complex factors and relationships; the scope of which may be better appreciated with reference to Larson and Pierce (1991) and Anderson and Gregorich (1984). They consider a quality soil has: i) an adequate capacity to accept, hold and release water to plants, streams and groundwater, ii) an adequate capacity to accept, hold and release nutrients and other chemical constituents, iii) a physical condition which promotes and sustains the unhindered development of roots, including conditions which promote aeration, iv) an adequate capacity to sustain soil biological processes, including the capacity to accept, store and recycle the energy contained in organic matter, and v) an adequate capacity to respond to management and resist degradation. Finally, there must be vi) an absence of unsuitable chemical conditions such as acidity, salinity, and toxic organic or inorganic constituents that would be deleterious to plant growth or food quality.

Soil quality change

Soil quality in time and space

This framework aims to provide a basis for the development of procedures for regional and national assessments of soil quality and soil quality change. As such, it must consider procedures for determining change over time at a particular site or local area and coupling these with procedures for extrapolating from point sources or small areas to larger areas. Hamblin (1991) suggests that all research methodologies are limited either by constraints of space, in that they are too specific to be extrapolated to whole regions, or by constraints of time, being measured over too short a period to be predictive of any long-term trend. She suggests that to extrapolate from point-sources of measurement in time and space requires some form of modelling or statistical manipulation.

An approach to address the time dimension in the above question is provided by Larson and Pierce (1991). They propose soil quality (Q) be considered as the state of existence of soil relative to a standard or in terms of degree of excellence and that it be defined as the sum of all of the individual soil qualities or attributes such as texture and organic matter. In that the maintenance and enhancement of soil quality require knowledge about changes in soil quality (dQ) and not solely the magnitude of Q, it is necessary to consider change to the sum of all soil qualities between two points in time. Individually, any soil quality may be aggrading or degrading, but it is the collective. impact of all soil qualities that determine dQ.

Through consideration of the dynamic change in soil quality, the relationship dQ/dt can be used as a measuring device for evaluating the impact of land management systems with respect to either soil degrading or soil aggrading processes. A minimum set of soil attributes could be chosen as indicators of soil quality and these could be monitored over time. These minimum data sets should be selected from those soil attributes in which quantitative changes can be measured in a few years time.

Alternatively, these data sets could be used to identify indirect measures of a soil quality attribute or groups of attributes which could serve as surrogate indicators of Q and, hence, provide a means of monitoring Q and its change in response to land management and soil degradation processes.

One approach to the evaluation of soil quality and soil quality change over large areas involves the selection of sites that are representative of the agricultural land resource areas and farming systems of the region or country and periodically measuring selected attributes important to soil quality at these sites. Alternatively, soil databases in combination with land-use and management information provide a basis for the assessment of soil quality wherever this information has been collected. In this approach, dynamic soil quality is predicted from information that describes land-use and management and models or other techniques that establish a quantifiable relationship between soil attributes and associated land-use and management.

Soil quality factors

The framework considers land management practices as the causes of change to a soil's quality and provides examples of soil processes that may be impacted by the various practices. It proposes that the considerable knowledge and analytical capabilities that have been developed to relate land management to soil degradation can provide a basis for determining the impact of land management on soil quality. This provides a focus for the selection of the most relevant processes and attributes and, in turn, the most appropriate set of criteria and indicators for the assessment of soil quality for any critical function. Elaboration of the land management and soil factors and the soil-modifying processes is provided below. Proposals for the development of criteria and indicators are presented in following sections.

Land management factors

Land management impacts on a number of soil processes that determine soil quality. Greer and Schoenau (in press) have listed crop type and rotation, tillage, traffic, and additions of fertilizers, pesticides and animal, human and industrial waste as examples of management practices that affect soil quality. He also has indicated the kinds of soil processes that are moderated by each of these practices (Figure 1). When used in conjunction with the factors determining soil quality enunciated above by Larson and Pierce (1991) and Anderson and Gregorich (1984), it is possible to select the most appropriate processes for assessing change in soil quality for each critical function.

Soil factors

Soil processes such as infiltration and respiration, which determine the soil's capacity to perform a specific function, and critical attributes such as soil depth and organic carbon content, which can be used to quantify these processes, are termed the factors of soil quality. Lists of these factors for each of the crop production and environmental functions have been developed (Figure 1). Consideration of these factors in developing criteria for assessing soil quality change recognizes that some factors are more important determinants of the capacity of a soil to perform specific functions. They are more responsive to land-use and management pressures, and are more easily measured than others and, hence, are more suitable for use as criteria for determining soil quality change.

Soil-modifying processes

Processes such as wind and water erosion, salinization, oxidation or mineralization of organic matter which degrade or aggrade the soil are referred to as soil-modifying processes. They are recognized as processes affecting soil quality for both critical functions (Figure 1). Water erosion, for example, has long been recognized to affect the critical function of crop production. More recent concern involves its effect on the quality of water in streams or lakes. The critical point, as it relates to the environmental function, is not whether water erosion is impacting on surface water quality but whether water

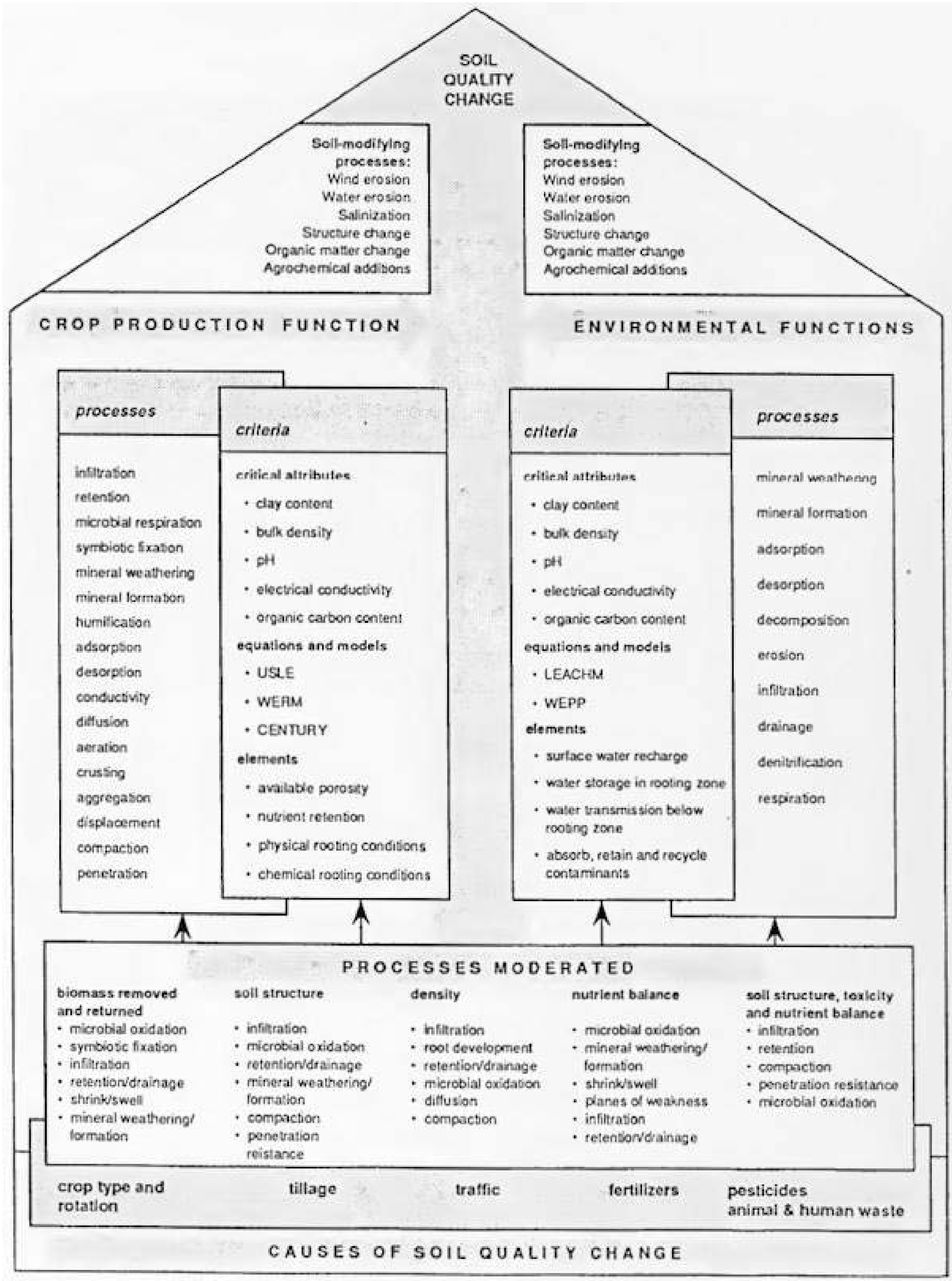


Fig.1 Outline of a procedure for selecting criteria for the evaluation of soil quality change.

erosion is impacting on soil quality by influencing its capacity to accept, hold and release water to plants, streams and other water bodies. These soil-modifying processes can be used to evaluate change to individual or composite groups of soil attributes that have been or will be established for the two critical functions.

Work is on-going in the development of physically-based simulation models for wind and water erosion, loss in soil organic matter, and in the development of models or alternate capabilities to predict change in soil quality related to soil structure change and soil salinity. Models have been developed to predict the movement of chemicals to groundwater and could be used to predict the fate of composted solid waste applied to agricultural land. These models have the capability to predict change to many of the attributes that determine soil quality and hence enable us to measure change to the capacity of a soil to perform a critical function.

Other dimensions of soil quality assessment

Assessment of soil quality, in essence, implies an evaluation of the capacity of a soil at a particular locale to perform specified functions. This is to say, the assessment addresses soil quality change within the boundaries of the ecosystem.

The suggestion by Larson and Pierce (1991) that soils interact positively with the environment external to the ecosystem in which they are located implies that assessments must recognize that the pedosphere is inextricably connected to the lithosphere, biosphere, atmosphere, and hydrosphere. A soil's capacity to function within that pedosphere, and, in particular to respond to land-use and management practices, will determine the potential for change to any of the related spheres (Arnold *et al.*, 1990). However, the framework is not directed to the assessment of soil-induced environmental change in a global context but simply to provide the capability to assess, if required, whether these environmental influences prevail in any particular assessment.

Within the context of this chapter, the assessment of soil quality change will focus on those man-induced changes directly related to the application of composted solid wastes to agricultural land.

This framework is generic in nature. In that it considers all crops to have the same basic growth requirements, it will be necessary to develop crop-specific approaches, such as those presented by Greer and Schoenau (in press) for implementation of the framework.

The utilization of the framework depends upon the scale of the assessment. For example, is the area of interest a field, a farm or some larger region.

Soil quality standards

The framework, to this point, identifies the factors that determine soil quality, but it does not place any comparative or judgement value on them. The final step of an assessment is to indicate the degree of excellence of the soil for the use in question, and the final step of monitoring is to indicate the direction and magnitude of change. As such, assessments require a standard for the comparison of soil quality and monitoring requires a standard for soil quality change. Before proceeding to an approach for the development of standards, a definition of a soil quality standard is required.

Soil quality standards
Standards of soil quality include any defined basis for determining a stated condition (or for comparing changes in soil condition) that indicates the health, quality, or productive potential of a soil for a specified use. They may also indicate a level at which the soil cannot suffer additional change without showing significant adverse effects and/or irreversible damage. These standards are use-specific and are not intended to be a rating or a limitation scheme for a particular use (soil capability and many other soil interpretations are different concepts).

The development of standards for soil quality requires consideration of criteria and thresholds and the assessment or monitoring of soil quality or soil quality change requires the development of indicators. The meaning and application of these and related terms are provided, as follows, as a basis for the full development of this framework.

Soil quality criteria
A criterion is a standard or a rule against which a judgement can be made. It may be a field or laboratory test or measure such as the determination of total soil carbon. It may be an equation that predicts soil loss from water erosion, or it may be a model that predicts soil salinization (Figure 1). As such, these criteria identify factors, numerical relationships, formulae or more complex models that provide a set of conditions or rules which enable us to observe, measure or predict the dynamic state of soil quality. They are the "rule-base" for a set of standards. For example, a standard could be established for levels of nitrate leached below the rooting zone. The same limit could be used for all soils or limits could be soil specific. A set of criteria would define the limits and, perhaps, how they would be applied in assessment and monitoring.

Thresholds
Thresholds are a particular form of a standard denoting levels beyond which soil quality undergoes intolerable and perhaps irreversible change.

Soil quality indicators

Indicators provide a set of measurable or observable attributes which reflect changes to processes and hence to attributes governing soil quality. They are often short-cuts to the development of rigorous criteria and standards for soil quality assessment and monitoring. A comprehensive capability to evaluate soil quality, as indicated earlier, would address the capacity of a soil to function for a specific purpose by evaluating all of the important attributes that contribute to this capacity.

It is impractical if not impossible to develop criteria that would address all of these attributes for all, perhaps any, evaluation. Instead, a limited number of key attributes are chosen to represent the condition to be assessed or the change thereto to be monitored. These key attributes or indicators take many forms, to be considered in the following in terms of soil quality attributes, surrogate or proxy indicators and soil quality elements.

Soil quality attributes
A soil quality attribute is a measurable soil property that influences the capacity of the soil to perform a specific function. An exemplary list of critical attributes is provided in Figure 1. Some attributes, however, are more suitable than others for measuring soil quality change. Attributes such as soil depth, soil organic matter and electrical conductivity are often selected to represent properties most affected by soil degradation processes (Arshad and Coen, 1992). Attributes that are

more sensitive to management are most desirable. Gregorich *et al.* (1994) proposed attributes such as microbial biomass, amino acids and soil enzymes as highly sensitive soil quality attributes.

Surrogate or proxy indicators

The framework provides the opportunity to select indicators that are either direct or indirect measures of land management practices that clearly impact on soil quality. Crop cover, including residues, exemplifies this type of proxy indicator; rates of addition of fertilizer, manure, or composted solid wastes are others.

Surrogate or proxy indicators of soil quality also may be derived from consideration of the soil-modifying processes. They include risk to soil erosion, compaction, salinization or they could include measures or estimates of soil loss from erosion or extent or severity of soil salinization, compaction, or contaminated land, for example.

Elements of soil quality

The critical soil functions described previously must be determined before soil quality can be assessed. These functions are scale-independent, remaining the same for plots, fields, districts or larger regions. The information used to assess soil quality, however, is dependent upon scale. This has necessitated the identification of scale-dependent components of the critical functions, termed elements of soil quality, as basic units of assessment.

Four soil quality elements have been established to provide a basis for quantification of the crop production function: available porosity, nutrient retention, physical rooting conditions, and chemical rooting conditions. Similarly, elements such as surface water recharge, water storage in the rooting zone, water release for plant growth, water transmission below the rooting zone, and the capacity of the soil to absorb, retain and recycle contaminants are proposed as elements for the assessment of the various environmental functions (Figure 1).

Assessment and monitoring of CSSSW

A framework for soil quality evaluation is shown in Figure 2. The pathways in such a framework are as follows:

1) Determine the objectives of the evaluation. Begin by establishing the critical soil quality functions that are important to the assessment. Are they related to crop production or to environmental protection, or both? What are the dimensions of the assessment? Is it related to a single event or to multiple events over a protracted time frame? Is it for a site, field, farm or for an extended region? Is it focused within the ecosystem boundaries or on the environment external to that ecosystem? Once the functions and dimensions have been defined, it is possible to initiate the selection of criteria. Final selection of criteria may require consideration of available data and data management capabilities.

2) Data collection and management. The specific data requirements will depend upon the purpose and the dimensions of the assessment, but they always will include soils, topography, climate, and land-use and management. In assessment or monitoring

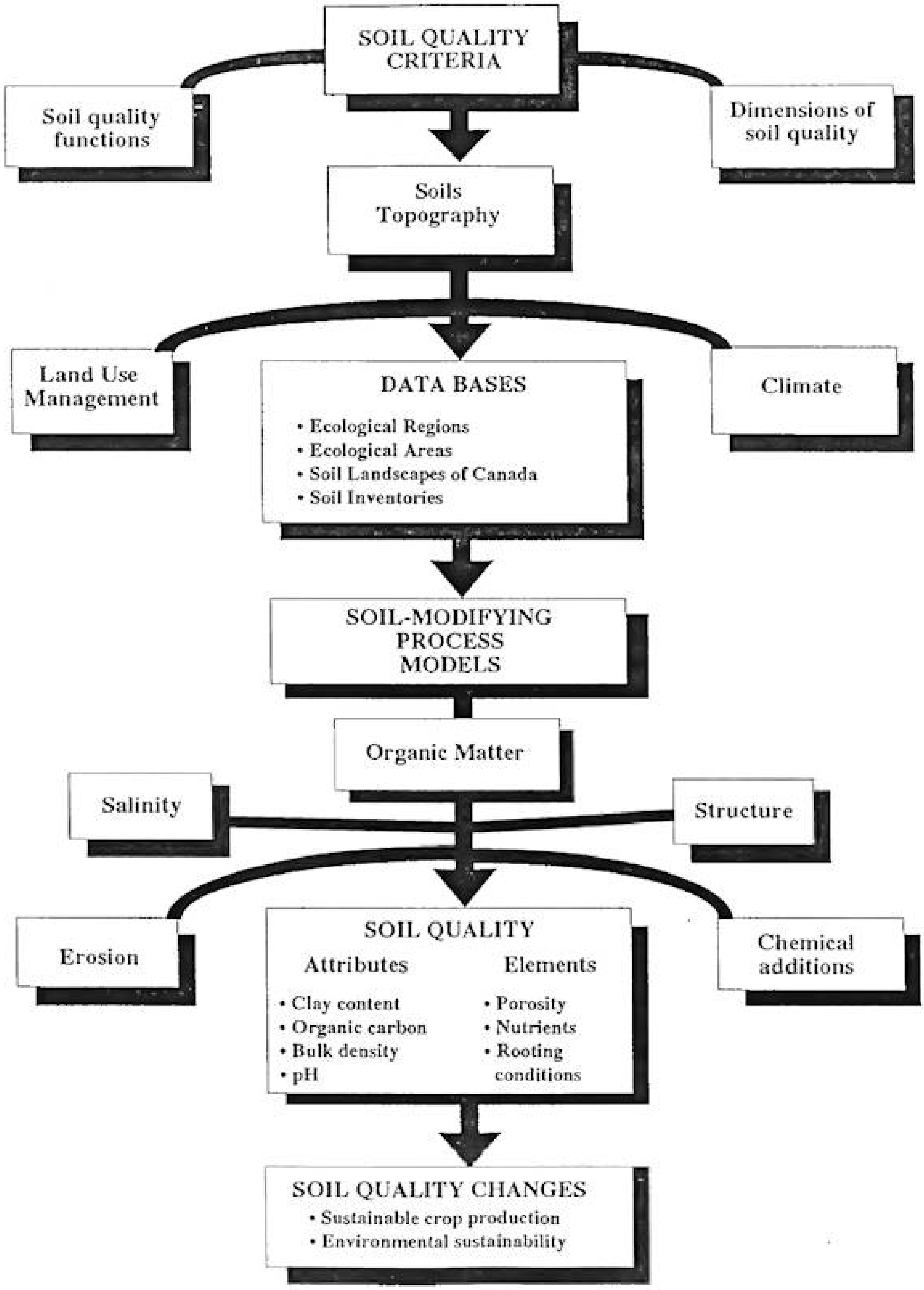


Fig. 2. Framework for soil quality evaluation.

over large areas, it may be advantageous to integrate the various data sets, that is, to organize the data so that each area under consideration has a description of all the relevant information. It also may be advantageous to organize the data so that the initial analysis can be conducted at a detailed scale with facility to generalize the information in the final analysis. "Nested databases", whereby groups of map polygons at a detailed or large scale fit, or, are nested within polygons at successively smaller scales, facilitate such analysis.

Make a final selection of the criteria for the assessment. The criteria are soil attributes contained in the database. They may be resident data or they may be data to be collected as part of the evaluation. They may be single attributes such as clay content or pH or they may be an integration of a number of soil attributes into more comprehensive elements of soil quality.

Predict the condition of, or change to, soil quality. A series of soil-modifying process models have been developed that could facilitate the analysis of change to soil quality in space and time. It is not always necessary or even possible to operate these models in their entirety. It is sometimes adequate to develop more simple mathematical relationships for this analysis.
The output of an analysis following this framework is a measured or predicted condition of soil attributes or elements that reflect a change to, or a new state of, soil quality.

Acknowledgements

The authors wish to acknowledge the many colleagues that provided suggestions and criticisms in the development of this framework, particularly: D. W. Anderson, M.A. Arshad, G.M. Coen, W.W. Pettapiece, and K.B. MacDonald. They also thank D. Mittleholtz and C. Stushnoff of the University of Saskatchewan for the preparation of illustrations.

CSSSW AND LAND-USE SITUATION IN CANADA (MacDonald, K.B. and F. Wang)

Typically, agricultural activities lead to a reduction in the levels of organic carbon in the surface layer of soils. As a result, the ability of the soil to retain and release nutrients is reduced and its capacity to maintain structure and to absorb water is degraded. The distribution of carbon across the landscape is quite variable. This fact coupled with the large amounts of crop residues which accumulate and decompose during the course of the year make exact quantification of soil organic carbon levels very difficult. However, recent land-use and management practices such as no-till and conservation tillage have increased the levels of crop residues which are retained on the soil surface and appear to have stabilized or reversed the trends of organic carbon decline in soils. At the same time, the increases in population in urban areas and the increased demand for livestock to provide food have resulted in accumulations of various organic residues (municipal and industrial solid wastes, sewage sludge, and animal manures). These materials make up a large volume of both municipal and agricultural wastes; they are high in carbon and generally must be disposed of by land application or in landfill sites. While improper handling of these materials may result in emissions of greenhouse gases (methane, carbon dioxide, or nitrous oxide), they constitute a readily available source of organic carbon which can be used to augment the current soil organic carbon levels.

For a variety of reasons (safety and health, quantity of material, etc.), composted biosolids are more attractive than their raw materials as a source of organic carbon. The most appropriate use of these materials occurs when they are applied to land areas where the benefits of additional carbon are greatest.

This chapter discusses general considerations related to agricultural land-use and management to provide a broad framework for the proposed series of composting trials. A detailed assessment is shown for Southern Ontario to provide an example of the analysis which could be carried out for Canada as a background to coordinated trials for application of Composted Source-Separated Solid Wastes (CSSSW) to agricultural lands.

The specific objectives of the chapter are:

1) to provide a context for planning the application of composted source-separated solid wastes (CSSSW) to agricultural lands. This general perspective includes aspects such as the potential quantity of material available and the proximity to agricultural land with appropriate characteristics of land-use and management,

2) to illustrate the use of a spatial framework for planning and implementation by suggesting a possible regime for land application of CSSSW which would produce measurable impacts on crop production and soil characteristics, based on the literature and agronomic knowledge,

3) to illustrate how existing databases could be used to assist with experimental site selection, and

4) to identify the kinds of detailed data which could be assembled to assist in the process of generalizing results from experimental sites to appropriate adjacent areas (scaling-up and establishing zones of relevance for the sites).

Context for planning the application of CSSSW to agricultural lands

In establishing a context for the proposed trials, land application of CSSSW is considered from the standpoint of

1) the potential quantity of compost which could become available,

2) the area and current uses of land available within practical limits of transport,

3) the general soil characteristics, and

4) for the agricultural land, the kinds of agricultural enterprises and associated management.

Potential quantity of CSSSW for agricultural lands

As the population increases the demands for food and fibre and the associated production of waste also increase. There are various categories of waste ranging from metals and glass to reusable goods as well as materials suitable for composting. Diener *et al.* (1993) report studies from the United States which show that between 30 and 70% of the domestic wastes could be composted. For Canada, it has been suggested that on average, about 250 kg of compost per person per year (agricultural and non-agricultural wastes) would be produced if the appropriate waste materials are directed into composting operations (P. Van der Werf, personal communication). If the population of Canada is estimated at about 28 million people then the potential amount of compost would be *7,000,000 tonnes per year.* Clearly, for the short to intermediate term, this figure represents the maximum amount available for use. A substantial proportion of the population will continue to get rid of waste materials in conventional landfill sites. Some of the population will compost some of the waste materials in individual or neighborhood composters for use locally on gardens and flower beds. In addition, some organic waste will be applied directly to land without being composted. Current studies (e.g., Edwards et al., 1994) are studying the efficacy of direct application of materials such as pelletized paper wastes for erosion control and mulches.

Area and current uses of land within practical limits of transportation

At a practical scale of operation the amount of CSSSW available for use will be substantial (both from a volume and a weight standpoint). As a consequence, it is important to develop uses for the CSSSW within relatively short distances of the sites of production. For animal manures it is suggested that the maximum feasible transport distance is about 20 km. For urban centres, there is a longstanding problem of transporting municipal wastes to landfill sites. As the current landfill sites become filled it is increasingly difficult to locate new facilities. Municipalities are showing willingness to transport uncomposted wastes relatively large distances. Figure 3 shows the locations of sites which were under consideration for the Greater Toronto area.

Sites were considered which were more than 60 km from the urban core. Diener *et al.* (1993) use a radius of 80 km (50 miles) to define the limits for transportation of CSSSW. For the purposes of this chapter, a distance of 50 km from the boundary of major urban areas was used to define the area of land with potential for disposal of CSSSW. Figure 4 shows the region of Southern Ontario which falls within 50 km of the major urban areas which can be distinguished from the AVHRR (Advanced Very High Resolution Radiometer) imagery. Approximately 70% of the agricultural cropland in Ontario falls within this limit. Figure 5 shows the corresponding region for the prairie provinces. For this region only about 18% of the agricultural cropland and 15% of the rangeland falls within this zone. On the other hand, the actual land area included in the prairie region is 9 million hectares as compared with 4 million in Ontario.

General soil characteristics

There are several ways in which compost incorporated into the surface layer of soil can be beneficial. Diener *et al.* (1993) identify aspects such as improvements in soil structure, aeration, permeability, water retention and infiltration, crop response and nitrogen use efficiency, suppression of soil-borne diseases and provision of macronutrient requirements. Many of these desirable results occur because the compost acts as a source of organic carbon to soils. Organic carbon amendments are most beneficial where the level of organic carbon in the soil is low either because of intensive agricultural activities or as a natural condition. The range of organic carbon in the surface layer of soils of Southern Ontario as recorded in the Soil Landscapes of Canada database is from 0.5% to greater than

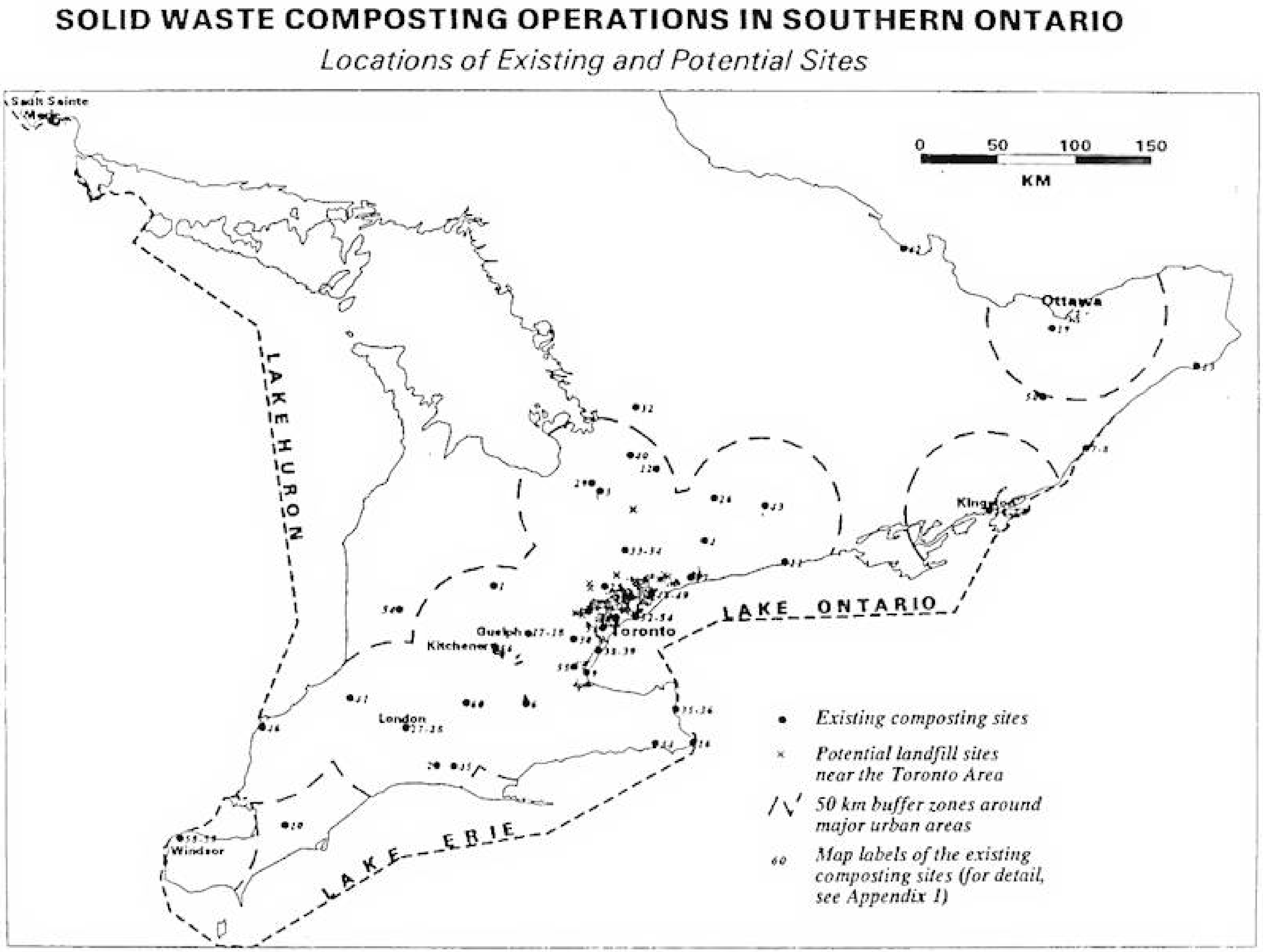


Figure 3. Solid Waste Composting Operations In Southern Ontario.

Figure 4

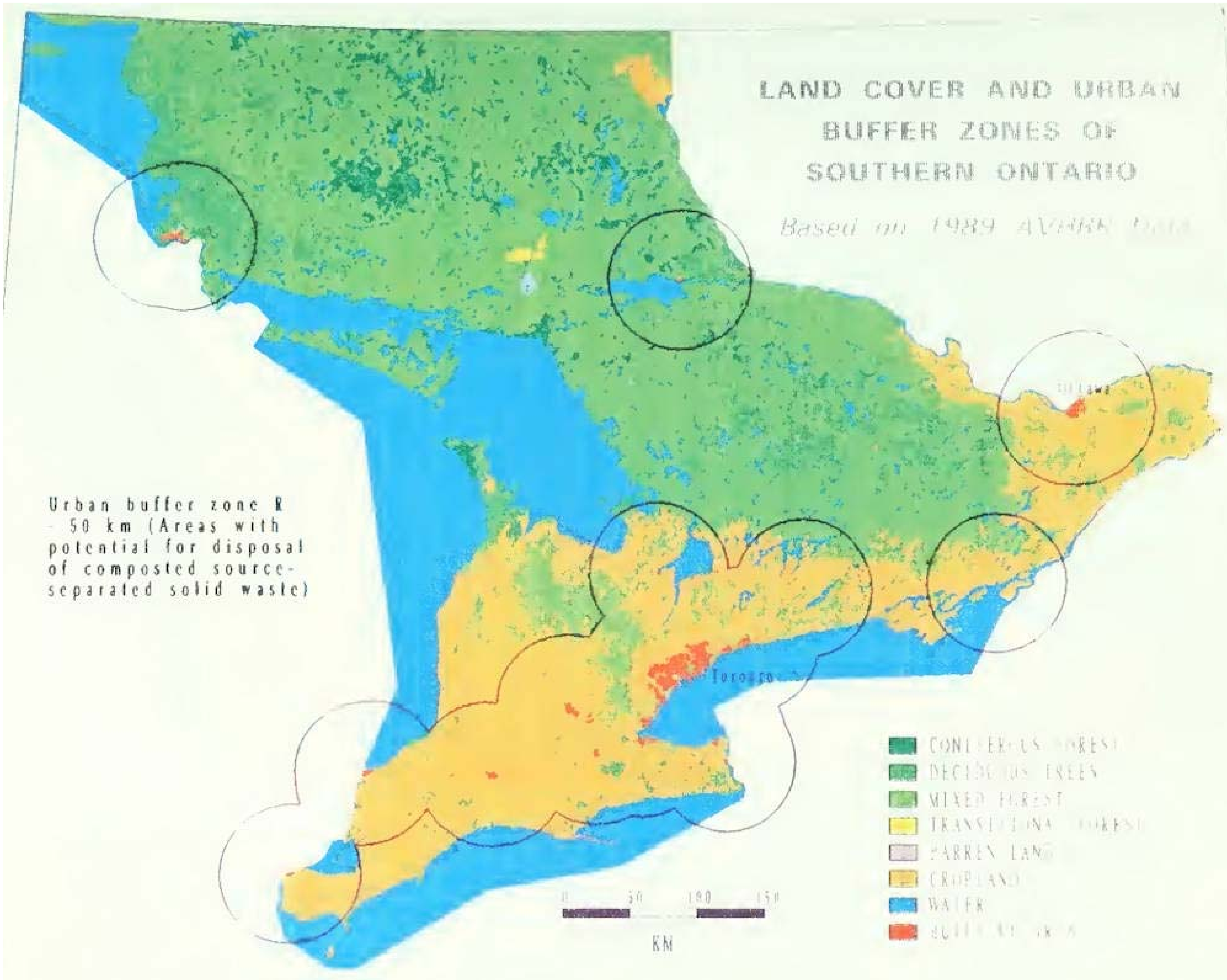
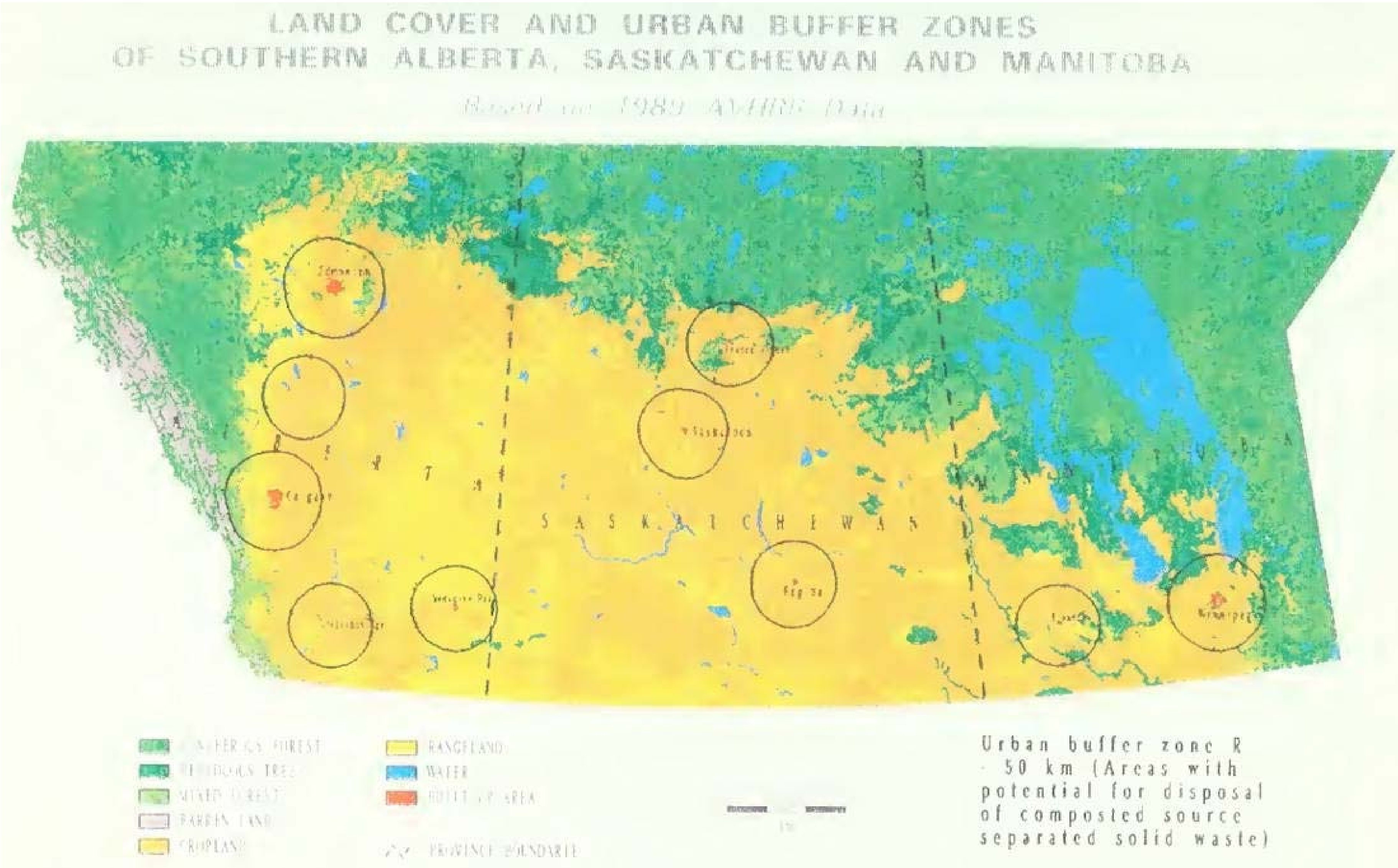

LAND COVER AND URBAN BUFFER ZONES OF SOUTHERN ONTARIO
Urban buffer zone R = 50 km (Areas with potential for disposal of composted source-separated solid waste)
Toronto
MIXED FOREST
WATER
KM

Figure 5


LAND COVER AND URBAN BUFFER ZONES
OF SOUTHERN ALBERTA, SASKATCHEWAN AND MANITOBA
S A S K A T C H E W A N
Urban buffer zone R
- 50 km (Areas with
potential for disposal
of composted source
separated solid waste)

5.5%. Most of the soils have an organic carbon content of less than 3% and about 30% of the area has an organic carbon content of less than 1.5%. Table 4 summarizes some of the important properties of soils in the 50 km buffer around some major urban areas in Ontario. Around all the cities except Windsor there is a substantial portion of the land where the organic carbon content of the surface horizon is less than 1.5%. Amendments of organic carbon provide benefits in terms of increased moisture retention and also improved structure and permeability. The benefits of increased moisture retention would be most important on the sand and sandy loam texture soils. These soils occupy significant areas around all urban areas except Windsor. Soils high in silt or clay would benefit most from organic amendments to improve structure. These soils predominate the region around Windsor and are common around the other areas as well.

Kinds of agricultural enterprises and associated management

Data from the 1991 Census of Agriculture were recompiled from the original enumeration area (EA) basis to the level of polygons on the Soil Landscapes of Canada (SLC) map. This was done by intersecting the centroids of enumeration areas with the SLC polygons and assigning data for an enumeration area to the polygon which contained the centroid. The data are approximate because the entire EA area will not be contained within the SLC polygon in all cases; they should, however, provide a reasonable approximation. Various aspects of land-use and management as recorded in the Census of Agriculture are summarized in Table 5. This table shows the land-use intensity for agriculture (area occupied by farmland) and the intensity of the agricultural activities (proportion of the farmland in annual crops). The data on livestock numbers provide an indication of the relative importance of cash cropping and livestock enterprises in the area.

An example regime for land application of CSSSW for National Compost Trials to achieve measurable impacts on crop production and soil characteristics

It is not the intention of this chapter to develop a detailed experimental plan for national compost trials. In fact, such a plan should be developed by a team of the experts who will be conducting the research in various parts of Canada. Clearly, the objectives of the trials would reflect regional differences; but, in all likelihood, there would be some common measurable objectives. The following section suggests some measurable objectives so that they can be used to illustrate how the rest of the planning exercise would proceed.

A twenty (20) year study is outlined wherein:

1) compost is applied for 10 years to:

- supply nitrogen for crop production (nutrient response would be evaluated relative to inorganic sources of nitrogen)
- substantially increase the level of organic carbon in the surface horizon of the soil (measurements would include soil properties related to structure, moisture retention, and infiltration as well as soil carbon levels).

Table 4. Soil Properties within 50 km Buffer Zone around Selected Urban Areas (expressed as a Percentage of the Land area).

	Ottawa-Carleton	Kingston	Metro Toronto including Hamilton	Kitchener-Waterloo, Guelph	London	Windsor
Organic Carbon in A Horizon - Less Than or Equal to 1.5%	27	12	51	54	46	-
Sand to Sandy Loam Surface Texture	32	38	36	20	16	5
Loam or Clay Loam Surface Texture	52	29	35	46	31	13
Silt Loam or Clay Surface Texture	15	27	23	32	53	75
Level Surface Form	25	17	11	6	5	72
Rolling Surface Form	9	-	22	11	6	4

Table 5. Land-Use and Management Practices within the 50 km Buffer around Selected Urban Areas (Based on 1991 Census of Agriculture).

	Ottawa-Carleton	Kingston	Metro Toronto including Hamilton	Kitchener-Waterloo, Guelph	London	Windsor
Total Land Area (ha)	438,000	303,000	1,252,000	752,000	1,252,000	139,000
Farmland (ha)	320,000	189,000	896,000	764,000	702,000	131,000
Cropland (ha)	182,000	80,000	613,000	588,000	572,000	123,000
Grain and Fodder Corn (ha)	50,000	12,000	156,000	198,000	231,000	30,000
Wheat (ha)	1,400	1,400	46,000	40,000	35,000	7,000
Soybeans (ha)	7,100	1,500	69,000	62,000	133,000	72,000
Livestock (animal units)	184,000	85,000	515,000	712,000	503,000	18,000
Manure Production (tonnes) (N content ~0.5%)	2,059,000	848,000	9,132,000	10,919,000	5,888,000	159,000
Area Receiving Manure (ha)	40,000	17,000	114,000	135,000	94,000	3,900

2) for years 11 to 20, no compost is applied

- the study site is monitored to determine the longevity and reversibility of the effects produced by compost additions.

Diener *et al.* (1993) suggest that compost could be applied at rates sufficient to meet the nitrogen requirements for annual crops. This would be achieved by an initial large application of compost followed by annual applications in lower amounts. The crop used by Diener *et al.* (1993) was corn which had a requirement for about 170 kg/ha per year. However, since continuous corn is not recommended, the discussion here will be directed towards an experiment where compost would be applied to supply approximately 70 kg/ha per year. This amount is sufficient to meet most of the requirements of winter wheat, or a grass based forage. It is more than required for soybeans but should not inhibit production of this crop. It could be supplemented with chemical fertilizer in years when corn was produced.[1]

This quantity of nitrogen corresponds to a first year addition of compost of 45 t/ha on a dry basis or about 75 t/ha at 40% moisture. Diener *et al.* (1993) estimate that this would correspond to a thickness of 1.9 cm. Diener et al. (1993) estimate that approximately 15% of the material will decompose every year which, at an estimated nitrogen content of 1% (P. Van der Werf, personal communication), would release 70 kg nitrogen/ha. In subsequent years, it would be only necessary to add compost to replace the 15% which had decomposed. Consequently, after the initial application, annual additions of compost would be 6.7 t/ha on a dry basis and about 11 t/ha at normal moisture contents. This would correspond to a depth of about 0.5 cm. From a logistical standpoint, it would seem reasonable to transport and apply compost at a rate of 11 t/ha. It would be necessary to conduct nutrient response curves using chemical fertilizers to ensure that the compost was supplying adequate amounts of nitrogen.

As mentioned earlier, there are several other potential benefits to application of compost to agricultural land; most related to increasing the organic carbon content of the surface layer of soil. Under average conditions, the surface 15 cm layer of soil weighs about 2000 t/ha. An organic carbon content of 1% corresponds to an amount of about 20 t/ha. The compost addition of 45 t/ha would increase the organic carbon level of the surface soil by about 10 t/ha or about 0.5%. (The carbon content of compost is approximately 24% (P. Van der Werf, personal communication)). This amount of carbon is readily measurable and should cause improvements in properties related to structure, water infiltration and retention. Diener et al. (1993) suggest a trial where compost would be applied for 10 years to supply a constant amount of nitrogen (in the example here 70 kg/ha) for crop production. After that time, the annual applications of compost would be discontinued, the residual compost would continue to release nitrogen and chemical nitrogen would be added to supply the growing crop. If a similar regime were followed in the Canadian trials, the amount of organic carbon remaining from compost in year twenty would be about 2 t/ha or approaching the limits of detection with a reasonable sampling schedule. The

[1] The quantities of nitrogen referred to here relate to Ontario cropping conditions as described in OMAF publication 296, 1993-1994 Field Crop Recommendations.

amount of nitrogen being released from compost would be about 10-15 kg/ha or within the range which is currently added to growing crops from atmospheric deposition (Rudolph and Goss, 1993).

The proposed trial would determine the benefits of compost additions to agricultural land and also the degree to which any effects are reversible. The total compost addition over the 20 years would be 105 t/ha on a dry basis or about 175 t/ha at 40% moisture. The average annual addition would be 5.27 t/ha of dry material or 8.8 t/ha at normal moisture content.

For a region such as metropolitan Toronto (with an estimated population of 2 million) it is estimated that the potential production of compost would be 250 kg per person per year (P. Van der Werf, personal communication). This would result in a potential compost production for Toronto of 500,000 t/yr. At the application rates suggested above, the area would require less than 100,000 ha of land for compost application. The results presented in Table 5 suggest that there should be many alternatives for selection of this quantity of land. On this basis, the land required for CSSSW is less than 40% of the land currently used for corn, soybeans and winter wheat. In fact, this is less than the area of cropland (138,000 ha) which falls within 15 km of the urban area.

One of the other statistics to note from Table 5 is the high numbers of livestock within the 50 km urban buffer area. As mentioned in the introduction to this chapter, a more general problem exists; namely, the management of large amounts of organic residues (including CSSSW, sewage sludge, and animal manures). Composting procedures are also being considered as a way of reducing the volume of animal manures which must be managed. Current research (R. St. Jean, personal communication) indicates that manures produced in Ontario have C:N ratios significantly below the optimum range for nitrogen retention. In addition, the starting moisture content for manures tends to be too high. There may be advantages in using source-separated urban organic wastes or CSSSW to adjust these properties of animal manures and allow them to be composted.

Use of existing databases to assist with selection of experimental study sites

From the practical consideration of transportation distance, land for application of CSSSW should be close to the site of compost production. Figure 3 shows the location of current and proposed composting facilities throughout Southern Ontario (the names and capacities of the composting facilities are summarized in Appendix A). Application of CSSSW to agricultural land would be of most benefit where the material would provide nitrogen for crop production and increase the soil organic carbon level to provide improvements in soil properties. The review of the properties of soil, land-use and management (Tables 4 and 5) shows that it should be possible to select sites where the level of organic carbon in the surface horizon is low (less than 1.5%) and the surface texture is either sandy (where compost additions would improve moisture holding properties) or contains high amounts of silt or clay (organic amendments may improve the structure and permeability).

Within the context of trials which are coordinated nationally, it may not be possible in all cases (particularly in the black Chernozemic soil areas of the great plains region) to identify sites where the organic carbon content of the surface horizon is 1.5% or less. The actual site selection should be based on the most detailed data available. Figure 6 illustrates how the existing databases of detailed soil maps could be used to identify potential study sites.

Generalizing results from experimental sites to surrounding areas (scaling-up and establishing zones of relevance for the sites)

The results from study sites will provide information about the specific combination of soil, landscape and agricultural practices for the site. There will be many detailed measurements related to crop yield and condition as a result of compost application for the specific rotation of crops used in the study. There will also be measurements of the effect of compost on a wide variety of soil properties and related environmental characteristics.

It will be most important to establish the area of influence associated with the site where compost is applied. It is to be hoped that the influence will be positive. For example, improvements in soil structure may reduce soil erosion, increase percolation through the soil and improve the quality of runoff water flowing into surface drainage channels.

As with any experimental study, the site specific results will need to be generalized. Obviously, it is not possible to do the generalization *a priori* but some indication of the process can be suggested as follows:

1) the existing soils database will be interrogated to determine other areas where similar conditions occur (an exercise similar to the site selection process shown in Figure 6).

2) in addition, areas where soils are somewhat similar can be defined to show where some of the effects can be expected

3) other layers of information can be used to build on the experimental results; for example, if compost resulted in increased flow of water into the soil, it would be relevant to show areas which are artificially drained. The application of compost would increase the flow in subsurface drains and the quality of water would have to be considered.

4) it is unlikely that the crop rotation used in the experimental study will be appropriate for all areas receiving compost; however, data from the Census of Agriculture could be interrogated to show the range of land-use conditions in the area and interpret how these would relate to the experimental conditions. In the example shown, the land-use and management information for polygon 56 (shown on Figure 6) is summarized in Table 6.

Summary

As the population pressures increase, the requirement for land application of organic residues (municipal and industrial organic wastes, sewage sludge, and animal manures) either in raw or composted form will become increasingly important. The application of CSSSW to agricultural land appears to offer benefits to the landowner while reducing the large volumes of organic material currently dumped in landfills.

Research is required to confirm the nature of the potential benefits and to establish environmentally safe and agronomically sustainable land application guidelines and procedures. This chapter shows how current spatial analysis techniques (Geographic Information Systems and spatial databases) can be used to support the planning process. It illustrates the extensive information about

the quality and quantity of land resources as well as their current use and management is available from existing sources e.g., the National Soil DataBase. In many cases the data are already in computerized databases.

The geographic approach provides a spatial framework for planning of research trials. Existing data can be used to develop experiments which are relevant to the general conditions of soils and agricultural land-use. In many cases, the existing data can be used to identify possible specific locations for field research.

Spatial analysis is also useful as the results of research trials are incorporated into guidelines for land application of CSSSW. Additional layers of data can be incorporated to develop maps showing target areas for implementation and zones of influence.

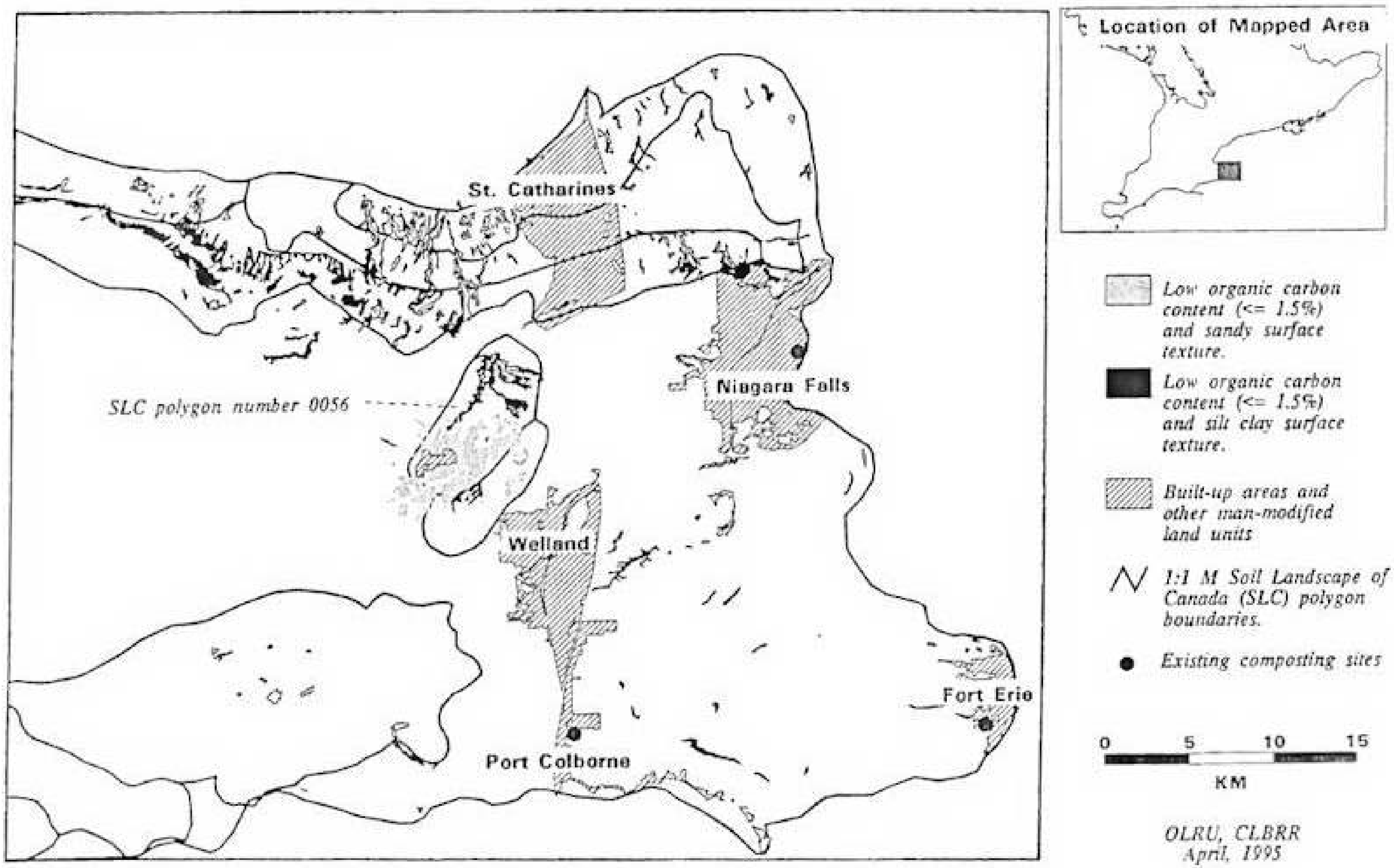
Table 6. Selected Census (1991) Attributes of SLC Polygon 56.

ATTRIBUTES	QUANTITY	INTENSITY
Land Area (ha)	4,182	n/a
Farmland (ha)	3,515	84% of polygon area
Cropland (ha)	2,268	65% of farmland
Corn (ha)	583	26% of cropland
Soybeans (ha)	601	3% of cropland
Hay (ha)	557	25% of cropland
Tree fruits (ha)	338	15% of cropland
Grapes (ha)	103	5% of cropland
Area receiving fertilizer (ha) of cropland	1,766	78% of cropland
Area receiving manure (ha)	388	17% of cropland
Area receiving herbicides (ha)	1,079	48% of cropland

Figure 6

POTENTIAL AREAS FOR SELECTING EXPERIMENTAL STUDY SITES OF CSSSW APPLICATION TO AGRICULTURAL LAND IN RM. OF NIAGARA

An Example of Spatial Identification based on Detail Soil Survey Data (1:25,000)



SPECIFIC RECOMMENDATIONS FOR THE NACT

What follows is a series of specific recommendations on topics which have been identified by the considerations of participants at the workshop. These are presented in the context of the conceptual framework and the land-use situation in Canada. Any lack of specificity and detail in these recommendations reflects the need for further discussions and developments.

Site specific studies

We recommend that the NACT consist of a series of site specific studies. A network of study sites is essential to provide a meaningful assessment of CSSSW on agricultural land and to provide a network of well-documented sites at which integrated multidisciplinary research could be developed. This will provide a direct measurement of changes associated with CSSSW application for various soil types, climates and production systems.

Study sites should be selected to represent major soil types, climatic zones and ecological regions. In addition, the sites should correspond to a major farming system within a region and the compost application should be designed to reverse soil degradation processes. The selected compost should be category AA or A of the CCME/BNQ Standards; however, in certain circumstances a rationalized alternative may be acceptable. We recommend that the selected sites be located on AAFC research stations to avoid liability issues and maintain control of the experimental plots. The sites should be located at close proximity to a reliable source of compost. However, the quality of the site and/or the compost should not be compromised. Moreover, we also recommend that a reference crop such as barley or oat, be included at each of the study sites and that sites be maintained for a minimum of 5 to 10 years.

The site specific study should be a multi-disciplinary study. It should include a component which relates to the agreed upon minimum data set requirements and another which reflects the specific available scientific expertise and regional issues. Project leadership and resources should be jointly provided by AAFC and the local partners. An effort should be made to promote the projects' visibility to local interest groups. Site specific studies should recognize the involvement of national interest such as the CCC, EC and AAFC.

Need for standard protocols

The assessment of CSSSW application requires that the compost be well characterized and that the appropriate soil properties are meticulously measured. For example, the maturity of compost, which is related to the degree of organic matter evolution, involves many processes and should be assessed using many different attributes. This is particularly important as organic matter is continuously changing and no single property, such as total C and N or C to N ratio, can be used to assess its chemical and biological reactivity within the soil system. The CCME/BNQ standard is an insufficient characterization of compost to determine impact on the soil-crop system. Compost and soil organic matter characterizations should also include; the degree of oxidation, enrichment in function groups, capacity to retain and release cations, degree of biodegradability, and reactivity to agrochemicals (especially pesticides and fertilizers) and other soil constituents (e.g., clay minerals).

It is essential that a standard methodology to characterize composts and soil organic matter be used at all the study sites. In addition we recommend that one laboratory be selected to supply this characterization. The use of standard methodology is also required for the determination of soil properties. The participants of the NACT should agree upon a standard set of protocols for soil, crop, water and compost characterization (for example, Carter et al., 1993; ASA, 1982-1986).

Minimum data set

Minimum data sets are required and should be collected at each site in addition to the data that is unique for each site specific study. Within the proposed conceptual framework, minimum data sets are required for basic chemical, physical, mineralogical, and biological characterization of the site and to monitor changes during the NACT. We recommend that the minimum data set include but not be restricted to the soil properties used in the national soil quality benchmark study (Wang *et al.*, 1994). They include properties with varying degrees of sensitivity to land management practices. An initial and complete survey of the site is recommended with periodic repeated sampling to monitor changes with treatment and time. These soil properties will provide baseline information for the various soil attributes and processes. Furthermore, we recommend that additional soil properties related to the dynamic nature of soil organic matter be added to the minimum data set (Table 7).

There should be a requirement for participation in the NACT that an agreed upon minimum data set be included in each site study. It should also be noted that a minimum data set will provide the link to existing databases based on soil properties and thereby a broader application of the findings.

Coordination

Coordination at the local or site level should be provided jointly by the AAFC scientist and the local partner. Coordination at the regional/ national levels is required for project initiation, funding, data consolidation and reporting. The type of coordination required will vary depending upon resource availability and the commitment of NACT project leaders to the NACT objectives.

At the very least a coordination role will be required for initiating projects and reporting progress. It is recommended that the CCC coordinate this by assisting local partners with the MII process and by providing a session for presentation and discussion of results at the CCC Annual Meeting on Composting.

Additional coordination will be required for various other activities if there is agreement amongst the participants;

1) Regional or centralized lab services and analysis of samples are suggested to ensure that samples are treated similarly and that standard methodologies are used. This will improve the capacity for data comparison within and amongst studies.

2) Data consolidation and association with other existing databases are required. Attempts to compare data amongst studies, either at the regional or national level, and to

Table 7. Recommended minimum data set for the NACT.

Sensitive soil properties [1]
Soil reaction (pH)
Available phosphorus and potassium
Organic carbon
Total nitrogen [2]
Bulk density
Dry-aggregate size distribution
Extractable iron and aluminum [3]
Cation exchange capacity
Exchangeable cations
Total and speciation of elements (arsenic, aluminum, boron,
cadmium, calcium, cobalt, chromium, copper, iron, potassium,
lithium, magnesium. molybdenum, sodium, nickel, lead, zinc)
Soil moisture retention
Organic matter characterization (*see* organic matter characterization)

Nonsensitive soil properties [4]
Carbonates
Particle-size distribution
Clay mineralogy [5]
Total surface area

Properties measured in the field [6]
Saturated hydraulic conductivity
Near-saturated hydraulic conductivity
Penetrometer reading and soil moisture
Electromagnetic ground conductivity [7]
Biopore and root counts
Earthworm counts [8]
Crop yields

Compost characterization
CCME/BNQ methodology
Organic matter characterization *(see below)*

Organic matter characterization
Distribution of carbon compounds (^{13}C-NMR CPMAS, Py-Fyms)
Quantification of functional groups
Biodegradability index of organic matter
Cation exchange capacity
Optical density of water and pyrophosphate extracts
Distribution of organic and inorganic forms of N
Nitrogen availability index

Site Characteristics
Site history (ecological setting and soils, parent material and surface form, cropping system, tillage system, fertilizer and pesticide use)
Soil map ca. 1:1500 scale
Contour map same scale as soil map With 0.1 to 1m contour interval, depending upon relief
Pedon description two representative soil descriptions per site
Pedon analyses including soil moisture desorption curves, and soil properties listed above for each horizon of the two selected pedons

1 Measured every year during study then every 5 years.
2 Most studies Will also need to measure organic N, NO_3- and NH_4-N
3 For Podzolic soils only.
4 Measured only at the beginning of the observation period to establish baseline data.
5 Heavy application of nitrogen and potassium fertilizer may alter some silicate clays and special studies may be needed.
6 Measured in the field annually.
7 Only in areas with potential salinity problems.
8 Except in the Prairie Provinces.

derive indices of compost impact and benefits will require a considerable effort. This effort will most likely involve cross referencing with the National Soil DataBase (NSDB). An obvious candidate for this role is CLBRR. CLBRR has developed considerable expertise in Geographic Information Systems (GIS), manages the NSDB, and has performed several similar analyses.

Funding

The R & D Matching Investment Initiative (MII) of AAFC is a Departmental initiative which is designed to increase the level of collaborative research activity between industry and the Department. The objectives of the MII are to: strengthen market-driven priority setting within the Department; accelerate the process of technology transfer; and increase the collaboration between government and industry in research. This is accomplished by entering into agreements with industry in which the Department matches industry contributions up to 100%.

The NACT is suitable for the MII program. A number of specific recommendations should be followed for the NACT:

1) It seems unlikely that AAFC will accept and process a single MII proposal for the entire NACT. Although there is a stated capacity for this type of approach, upper management within the Research Branch indicates that because the sites are scattered across the country there will be a need for considering regional priorities. It should be noted that MII applications will be compared to other applications and priorized according to established and developing mandates. As a result the MII will have to be presented, at the very least, on a regional level and most likely to the AAFC Research Station. Another consideration is that it may take some time for all potential participants to be "on-board" and ready to contribute. This would hold up the initiation of other projects.

2) A separate MII application should be made for each site within the NACT. The CCC should be a partner in each of the MII's and the application should be presented to the Director of the interested AAFC Research Station. Each local partner should obtain the MII kit and application form from the AAFC Research Station. The general format of agreements is similar and requires a project outline.

3) The CCC should act as a "broker" for all NACT related MII's. The application for the MII should include documentation from the CCC which outlines the NACT, other sites involved in the MII, and the proponent sponsors. In this way the priority assigned to the MII and the likelihood of receiving MII funding would be enhanced. Furthermore, this approach would also enhance CCC's ability to require that CCC funded studies include certain NACT components, e.g., minimum data set.

4) AAFC funds allocated to the MII will double next year (1996/1997) and there are still 1995/1996 funds available. Site study leaders should be encouraged to proceed.

Cost per site

A total cost per site per year to carry out site specific studies is difficult to determine. It will depend on many factors including; existing facilities and infrastructure, the agricultural issues of the region, and the scientific interests of the participants. The total cost will consist of both "in-kind" and cash contributions. The various costs include, salary for project leadership and technical services, operations and maintenance costs, and equipment needs. This total cost per site should range between $50,000 and $150,000 per year.

There are several assumptions related to the cost:

1) CCC will provide cash for parts of the project which deal with common interests and needs which apply to all sites within. the NACT; minimum data set, reporting and travel to annual conference, and technical support for data collection and analysis.

2) The Local Partner will provide both cash and in-kind contributions to each project. The cash will be used on site specific aspects of the project. The in-kind contribution includes project leadership and provision of the compost.

3) AAFC will also provide both cash and in-kind contributions. The cash will originate from the MII of AAFC and will be used to hire project personnel and pay operating costs. In-kind contributions include additional project leadership, and plot person activities.

Summary

The development of a design for the NACT is a major task when one considers the various regional agroecosystems, the heterogeneity of available composts, and the diversity of regional interests and issues. We suggest a focus on soil quality for the assessment of CSSSW impact and benefits. We do not intend to exclude issues related to food safety or environmental risk. The proposed conceptual framework provides a flexible structure to organize our knowledge. Moreover, the approach can be used to assess the indirect impact of compost additions on water and food qualities.

The conceptual framework approach offers an excellent way to achieve the objective of the NAGT without imposing a rigid framework, which may be found inadequate and counter-productive in many circumstances.

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Macdonald Campus, McGill University
Ste-Anne de Bellevue
Québec, Québec.

Dr. Charles Bourque
Moncton University
Moncton, New Brunswick.

Dr. Bruce MacDonald
Guelph Soil Survey Team
Centre for Land and Biological Resources Research
Guelph, Ontario.

Dr. Fenghui Wang
Guelph Soil Survey Team
Centre for Land and Biological Resources Research
Guelph, Ontario.

Dr. Régis Simard
Soils and Crops Research Centre
Ste-Foy, Québec.

Dr. G.A. Padbury
Saskatoon Soil Survey Team
Centre for Land and Biological Resources Research
Saskatoon, Saskatchewan.

Mr. Terry Goodyear
Centre for Land and Biological Resources Research
Ottawa, Ontario.

Dr. Henri Dinel
Centre for Land and Biological Resources Research
Ottawa, Ontario.

Dr. Sherman Nelson
Centre for Land and Biological Resources Research
Ottawa, Ontario

APPENDIX 2 ONE PAGERS

The following are the one pagers handed in by participants of the workshop. In preparation for the workshop participants were asked to prepare a 10-15 minute presentation and one pagers which defined:

- related on-going research activities at their organization and within their region (generally, there was one AAFC research scientist and one representative identified by the Composting Council of Canada per province).
- perception and thoughts regarding what research activities are required in their region before CSSSW use can be recommended.
- what agricultural problem the application of CSSSW will solve.

The original format of these one pagers has been modified for this report.

Waste applied to agricultural land
Dave Grimmett AAFC, Charlottetown

Current research:

A project using agricultural compost made from cull potatoes, straw, sawdust and manure in a 3 year rotation of potato, barley, and red clover is being conducted at Harrington P.E.I. by Roger Henry, John MacLeod and Brian Sanderson. We have one more year to complete a 4 year rotation trial to establish the optimum time of application of compost.

Early results show that 25 tonnes per hectare on potato fields show a positive yield response and that up to 30 tonnes per hectare can be applied without any negative effects on the crop. Heavier applications result in disease problems such as scab and rhizoctonia.

The compost used was of Very good quality with an analyses of approx 1.0% N. When added at 30 tonnes per hectare, a full crop of potatoes was produced without added fertilizer N.

Source of CSSSW:

The East Prince Waste Management Facility site manager Roger Henry started composting source separated domestic garbage this fall and will have plenty of product to work with. Roger is more than willing to cooperate in research involving the use of domestic compost applied to agricultural land. Some industrial composting projects he has been involved in include fish-peat moss, blueberry waste, Vegetable processing waste, waste french fry oil from Cavendish Farms and oil contaminated soil.

Areas where CSSSW and industrial compost could be beneficial:

Composting fits in with our rotation program. John and Brian feel that the use of compost in cropping rotations could help rehabilitate soils that have been degraded due to poor cropping management.

Since the cost of handling compost makes it less attractive than commercial fertilizer, some research should be aimed at showing farmers the other benefits of using compost, such as restoring the OM to the soil, slow N release, moisture retention, etc.

Also there is concern (stigmatism) connected with the application of industrial waste to farmland with the main concern being the buildup of metals or other toxic materials. Therefore a small scale "loading experiment" could be conducted if such elements or compounds show up in the analyses of the product.

Another problem that could be solved is the stripping of topsoil from agricultural land for landscaping in urban development. The use of compost could help in two ways. 1.) By mixing compost with subsoil or other types of fill. 2.) By restoring removal sites and sod farms.

Charles Bourque
Université de Moncton, Moncton, N.B.

On-going research activities:

1- Pulp and paper mill sludge composting
   1994 - 200 tonnes re. C/N, aeration, N sources, etc.
   - metals, pH, %H_20, %O_2, NPK, temp., etc.
   1995 - 36000 tonnes PPMS + other mill wastes

2 - CCME/BNQ quality standards re. analytical methods
   Assessment of acid digestion procedures
   Assessment of sampling protocol

3- Metal mobility from MSW compost
   Compost Sc. & UtiL, Vol. 2, No. 3, pp. 83-89 (1994)
   "Sequential Extraction of Metals Found in MSW-Derived Compost"

4- Biosolids in fabricating soil blends

Research required:

1- metal concerns, mobility, plant uptake, leachability

2- advantages of CSSSW re. soil quality, fertilizer usage, etc.

3- product consistency concerns

Compost studies at Sainte-Foy
Regis R. Simard, AAFC

The Sainte-Foy Research Centre has been involved in compost research for many years. We have just completed a two year study involving the use of Municipal Waste compost and paper mill waste (biosolids) composts in sod production with Laval University and private partners.

This study revealed that compost increased sod establishment, root and shoot yields, immobilized a certain amount of N and P, increased K availability, and resulted in elevated amounts of soluble nitrates and phosphates in the subsoil. The lead content of the compost is larger than the accepted value for agricultural use of sewage sludge in Quebec.

We are in the second year of a project aiming at the agricultural and environmental evaluation of 30 different composts (mostly from manure) both in the lab (detailed characterization) and under field conditions (bread wheat production). This project is carried out with private composting corporations and the Centre d'Agriculture Biologique of La Pocatiere. Composts were more effective in a sandy than in a clay soils. They resulted in large N immobilization from an increased microbial biomass. A compost made of peat and chicken manure was the best amongst 4 tested materials.

A third study involves the use of composted manure in corn production and is carried out in cooperation with the Quebec cash crop association. Composted manure is more effective when applied in the previous fall at cereal harvest. Its inorganic N fertilizer equivalent is inferior to uncomposted manure or liquid hog manure. However weed populations are less in the composted treatments.

A fourth study will start in January with a private partner to develop an organic fertilizer for golf greens and this is supported by the matching program.

There is a lot of work already published/done on composts and some questions still remain?

- dynamics of plant nutrients (N and P) and metals (particularly on acidic soils) bio-availability
- impact of biosolids on soil health (biodiversity, presence of pathogens)
- impact of biosolid application on groundwater quality in cool and humid climates.

J.D. Gaynor, C.F. Drury, C.S. Tan and T.W. Welacky
AAFC, Harrow Research Centre

Expertise:

The Harrow Research Centre has established itself as the centre for developing sustainable agricultural management practices related to improvement of water quality with respect to nutrient and herbicide use. The research team collectively has over 50 years experience in integrating agronomy, water management, soil biochemistry and weed control expertise. In the solution of water quality problems associated with agricultural practices in southwestern Ontario, earlier work centred on the suitability of sewage sludge from Water Pollution Control Centres for use in agricultural production.

Regional Activities:

The Essex Region has been actively involved in programs to reduce the quantity of material land-filled. Cardboard, tires, wood products and to a limited extent sewage sludge have been excluded from landfills. Waste reduction by burning has also been implemented. Aluminum, paper, used motor oil and plastic wastes are being recycled. Household wastes are being composted in backyard recyclers for utilization in home gardens and flower beds. Research is now being directed to reduction of curbside waste by separation and composting.

The Essex-Windsor Solid Waste Authority has initiated a pilot project on the feasibility of centralized and decentralized collection of curb wastes. The material is separated and composted then utilized by Windsor Public Utilities Commission (PUC) in parks and recreational areas. The project is expected to be completed in September of 1995. It is projected that Windsor PUC can accommodate the expected volume of composted waste from this region for a number of years. Thus, little interest is indicated in utilizing agricultural land.

A local environmental corporation receives unprocessed waste from a food processor. The material (about 10,000 tons) is currently disposed on agricultural land. Other technologies including composting are being considered. A London based environmental group is processing curb waste with intent for agricultural use. Finished material is expected this fall but no markets have been established. Paper sludge waste is being produced by another industry with the intent to evaluate the material for suitability as an agricultural amendment at several sites in southern Ontario.

Concerns:

The major impediment to CSSSW utilization is marketability. Users are cost conscious with little interest in purchasing soil amendment materials. The heterogeneous nature of the material will require chemical analysis of each batch of finished product for fertilizer Value and metal content. From these evaluations the value to agriculture and crop selectivity will need to be determined.

Solutions:

The impact of CSSSW in agriculture is unknown. The finished product will need to be evaluated for its nutrient or soil amendment characteristics to determine marketing strategy. At Harrow we propose to evaluate response of field or Vegetable crops to finished product. Changes in soil properties (bulk density, water stable aggregates, nutrients, water holding capacity and organic matter quality) will be evaluated to determine soil building or enhancement characteristics of the material. Optimum rates of application for selected crops will be determined. Emerging technology will be presented to growers at field days, conferences and other promotional events.

Organic amendment studies at Lethbridge Research Station

F.J. Larney, AAFC

The studies may be divided into two main groups: (1) Use of organic amendments in restoration of productivity to artificially eroded soils. (2) Effect of long-term annual application of cattle manure on soil and water quality under dryland and irrigated management.

Organic Amendments and Restoration of Soil Productivity:

1. Comparison of cattle manure, fertilizer N and P, and 5 cm topsoil addition in restoration of productivity to soils artificially eroded to 0, 5, 10, 15 and 20 cm depth. F.J. Larney, H.H. Janzen, C.W. Lindwall and R.C. Izaurralde (Univ. of Alberta).

   Initiated in 1990. Four sites in southern Alberta, two in the Edmonton area. The manure rate was 75 t ha^{-1} wet weight as a one-time application in the first year of the study.

2. Comparison of four rates of cattle manure (0, 24, 48 and 72 t ha^{-1}, wet weight) combined with three rates of P_2O_5 in the restoration of productivity to soils artificially eroded to 0, 10 and 20 cm depth. F.J. Lamey and H.H. Janzen.

   Initiated in 1992. Three sites in southern Alberta. Manure was a one-time application in 1992.

3. Livestock manures, crop residues and chemical fertilizer amendments for the restoration of productivity to a soil artificially eroded to 15 cm depth. F.J. Larney and H.H. Janzen

   Initiated in 1992 at Lethbridge. Livestock manures are: fresh cattle, old cattle, composted cattle, cattle + wood shavings, hog, and poultry. Crop residues are: alfalfa hay, pea hay and barley straw. Fertilizers include 200 and 400 kg ha P_2O_5. All amendments were a one-time application 20 t ha^{-1} dry weight in spring 1992.

4. Cattle manure and the restoration of productivity to land artificially eroded by land-levelling in 1957 to create non-eroded, moderately eroded and severely eroded plots. F.J. Larney, J.F. Dormaar and C.W. Lindwall.

   There were three separate experiments on the monitoring of residual effects of manure applications on wheat yield. Manure was last applied (a) in 1980, (b) in 1984 and (c) in 1990.

   (a) The residual effects of a one-time application of 15 t ha^{-1} of manure to moderately and severely eroded soil in 1980 is being monitored.
   (b) The residual effects of manure (30 t ha^{-1}) and fertilizer applied to a wheat-fallow rotation in 1980-85 are being monitored. Manure was applied in the fall of the fallow year (1980, 1982 and 1984) to non-eroded, moderately eroded and severely eroded land.
   (c) Residual effects of manure (40 t ha^{-1} in fall), fertilizer and straw applied annually for continuous cropping to wheat (1987-91) on non-eroded, moderately eroded and severely eroded land.

Long-term Application of Manure and Soil and Water Quality;

1. This experiment was initiated in 1973 at Lethbridge by T.G. Sommerfeldt and is currently managed by C. Chang. Annual manure application rates are: 0, 30, 60 and 90 Mg ha^{-1} on dryland and 0, 60, 120 and 180 Mg ha^{-1} on irrigated land. Soil and water quality changes are being monitored.

2. General measurements in all experiments: Crop yields, soil physical properties (aggregate stability, soil water), soil chemical properties (available N and P, organic C).

Projects at the University of Alberta,
Jerry Leonard, University of Alberta, Edmonton

Scientific expertise exist for Agricultural Engineering. Environment control systems for intensive animal production. Waste management systems. Engineering aspects of compost systems for agricultural wastes. I have a particular interest in the physical properties of compost, how these are relevant to the production and use of compost, and how to measure and describe them.

Title: Sustainability of manure management: nutrient retention and cost-benefit analysis

Summary: Evaluation, by nutrient retention efficiency and cost-benefit analysis, of the sustainability of slurry- and compost-based management of manure from dairy cows. Manure composted with straw as a carbon source and bulking agent. Nutrient balance developed on basis of measurements of C and N in exhaust air from composting vessels and C, N, P and S in subsamples of compost. Investigators: W.B. McGill, R. Janzen, J.J. Feddes, J.J. Leonard, N.G. Juma, J.J. Kennelly, S.R. Jeffrey

Title: Cold climate composting systems

Summary: Composted manure/straw mixtures are being used to study the effects of cold temperatures on the composting process with the aim of developing a better understanding of the thermodynamics and biological processes involved. Also, the application of compost to frozen and snow covered soils are being examined to evaluate nutrient availability and use. Investigators: J.J. Leonard, W.B. McGill, J.J. Feddes, R. Janzen

Title: Physical properties of composted wastes

Summary: Definition of the physical properties of materials that are of importance in the production and utilization of compost. Using compost obtained from laboratory, pilot-scale and full scale facilities, development of suitable standard methods of measuring these properties. Determining the factors that affect physical properties so that they can be controlled and manipulated in the optimization of composting processes. Investigator: J.J. Leonard

Other related research in region / province:

University of Alberta: Department of Civil Engineering - Environmental engineering group. Recent MSc thesis (by Joe Feehan supervised by Dr. Chris Ziess) on kinetics of yard waste, windrow composting processes.

Olds College: Composting technology centre. Recipe formulation for the composting of various industrial, municipal and agricultural wastes. *See* Tom Clarke's report.

Alberta Agriculture Food and Rural Development:
Starting this spring, in association with a major broiler producer, a trial/demonstration project will be carried out on the composting of poultry mortalities under Alberta conditions. Temperatures and pathogen survival will be monitored.

Agriculture and Agri-Food Canada:
Lethbridge Research Station. Use of compost in the reclamation of eroded soils. *See* Frank Larneÿ s report.

Agricultural problems to be solved by the addition of composted source separated organics to agricultural lands (consider regional and national issues).

Comments:

The main benefits of compost are likely to stem from the addition of organic matter and the resulting improvement of soil structure. Hence, composting is likely to have a beneficial effect in erosion control, water holding capacity and the efficiency of water use in irrigation. Also, use of compost might result in significantly reduced energy requirements for tillage and, maybe, reduced wear of soil-engaging components.

One of the real challenges in the proposed trials is to get everyone talking the same language. This problem is likely to be quite acute in the characterization of the physical properties of the Various composts. Nevertheless, the problem should be addressed so that we can compare "apples with apples". The list of properties that could be specified is long but, as a minimum starting point, I would suggest moisture content (wet basis), bulk density (wet or dry basis??) particle size distribution and perhaps water holding capacity and porosity. Since there are no established standards for determining these for compost, it might be worth looking at the use of the CSSSW methods for soils, ASTM methods for peat, and other sources in the literature. Please let me know if I can be of assistance in this.

Anthony K. Lau
Bio-Resource Engineering, The University of British Columbia

Scientific expertise consists of waste management and controlled environments

On-going related research activities

Project #1: An optimized process control strategy for the control of odors from composting facilities. Collaborators: Biowaste Management Ltd., Aldergrove, B.C.; Microbiology Dept, UBC

Objectives:

1. to identify and quantify the malodorous compounds;
2. to correlate odor emission with compost characteristics and composting environmental parameters;
3. to evaluate the performance of biofilters; and
4. to develop an optimized process control algorithm for odor reduction.

Approach:

Odor emissions from composting facilities can threaten their existence. The optimized process control algorithm takes into account the synchronization or compromise in control actions for minimizing odor generation while maximizing compost quality. In this regard, the project is related to project #2 as described below.

Project #2: Conversion of biological wastes to industrial products

Objectives:

1. to measure the physical, chemical' and biological properties of composting materials;
2. to correlate these characteristics with compost maturity and quality;
3. to develop a process control algorithm for Improved compost quality; and
4. to recommend a cost-effective, on-site composting system.

Project #3: Pre-design of an organic demonstration farm collaborator: Eco-Tek Waste Treatment Inc., Vancouver, B.C.

Objectives:

1. to compare the existing in-vessel composting systems in terms of process efficiency and product quality;
2. to conduct an engineering economics analysis of the systems; and
3. to recommend the most promising solution for implementation of the final design.

Approach:

Organic farming requires a very high quality of compost as fertilizer and soil conditioner. This project will lead to the final design of a mini-scale in-vessel composting system. Composting materials are manure, food waste and yard waste.

As compost quality depends on the composting process, which is in turn dictated by economics, the design will strive to produce a Category A compost with minimum capital and operating costs.

Agricultural problems to be solved:

Leachate from fertilizers or manure application to agricultural lands is a major concern. The addition of compost with slow-releasing nitrogen may provide a partial solution. Compost can also improve many aspects of soil quality. Stable compost can suppress plant pathogens and improve plant resistance to disease because of colonization by beneficial microorganisms during the latter stages of composting.

National Agriculture Trial CSSSW

John Paul, Pacific Agriculture Research Centre (Agassiz)

I do think that the issue of application of municipal and industrial waste compost needs to be addressed. The composting is already happening and being encouraged. Where will all this compost go? Here are a few suggestions or comments regarding the proposal as we understand it.

1. It is difficult to get useful information from many different sites across Canada, in experiments using different composts on different soils, run by different scientists with different expertise and objectives. In my opinion, if there is work to be done with compost or industrial wastes, it should be done at 2 or at most 3 research centres in Canada, each in different climatic zones. Each of these centres should be able to test compost application on at least 3 or 4 different soil types. This would provide much more meaningful scientific information because a similar compost can be compared on differing soil types and there is more coordination between sites.

2. The first concern that the public of Canada has when they think of the use of municipal or industrial compost on agricultural land is metals. Although the suggestion is to use Class A compost (lowest in metals), the concern is still there and needs to be addressed. What about long term application of compost containing "low" amounts of metals? In my opinion, metal work must be done and it must be done at one place (Ottawa). The instrumentation (IAP) for metal analyses is very expensive, and the analyses requires an experienced operator.

3. It is not clear from the presentation notes what information will be integrated using NSDB, GIS and mathematical modelling. Organic wastes have been used for centuries, we do understand many of the dynamics that happen when they are applied. The effect of the addition of composts has also been studied at some length. The only unique aspect of municipal or industrial solid wastes are the metals, or other potential toxic substances that they may contain. If any modelling is required it should focus on either toxics or metals.

4. In accepting to do this work on compost application to agricultural soil and the potential environmental implications of it, are we indirectly supporting a suggestion that there are no potential environmental concerns in the composting process? What about the high ammonia losses during composting? What about losses of other N gases like NO_2 and N_2O? What about

the potential for ground and surface water pollution during the composting process? This is of course not our mandate directly but we have to accept some responsibility for the composting process if we are to support the use of compost on agricultural land.

I support the concept of initiating more research in the use of compost on a national level. I also have some expertise on composting and the use of compost and am willing to participate in this initiative. It is not one of our research priorities at this time at the Pacific Agriculture Research Centre (Agassiz). In discussions with the province, we have concluded that there is enough animal manures produced in the Fraser Valley to effectively provide enough nutrients and organic matter to agricultural soils in the valley. This means that we cannot promote the use of municipal or other wastes for use on agricultural soils in the Fraser Valley. Because these wastes are "subsidized" (paid for through taxes or dumping fees), municipal or industrial wastes are more suitable for export out of the valley for use on forested lands or rangeland.

Gerrie Neilson at Summerland has also expressed interest in being involved with this work. He has had experience already with the use of these wastes. Summerland is also located in an area where there is little livestock therefore there is little "competition".

Lawrence van Vliet, located at the Pacific Agriculture Research Centre (Vancouver) has experience with measurement of surface runoff from soil following applications of manure. He may also be a good resource.

The Pacific Agriculture Research Centre (Agassiz) is located in as area of Very high rainfall and a mild climate, which does raise some unique questions about the environmental implications of compost addition to soil. If money were available, trials could be set up here, but as mentioned earlier, it is not one of our station's priorities at this time.

Mycological perspectives for a National Agricultural Trial under the compost initiative

John Bissett and Keith Seifert, CLBRR , AAFC

Health Risk Assessment

The most important mycological concern in any study involving self-heating compost is the probable presence of a human (and animal) pathogenic fungus called *Aspergillus fumigatus,* a risk that we note is not yet included in the Environment Canada compost standards. This is a very common fungus in most self-heating composts, and often becomes the dominant fungus. It would presumably be killed in those parts of the compost that heated above 65°C. In addition to invading and killing lung tissue (allergic bronchopulmonary aspergillosis and aspergilloma), *A. fumigatus* also produces mycotoxins (gliotoxin, spinulosin, phyllostine, fumigatin, trypacidin, fusigen, ferricrocin and fumgacin) that can be inhaled along with the spores, and provokes hypersensitive responses in some individuals (cf wood chip burner's lung, farmer's lung, greenhouse lung). There have been serious problems in New York State concerning *A. fumigatus* proliferation in urban composting facilities leading to epidemiological studies on asthma in those areas, and active anti-composting lobby groups. Assays for this fungus should be included in the experimental plan for this project, at least for the starting compost. Furthermore, we recommend that field workers working with compost in these experiments follow the federal guidelines for handling contaminated grain, i.e.

wear overalls, gloves and particle masks. Because *A. fumigatus* is thermotolerant, it can be isolated rather easily by incubating spread or dilution plates at 40°C-50°C. It is relatively easy to recognize on isolation plates and could be identified reliably by a technician. The possibility of monitoring the population levels of this fungus as the field experiment progresses should also be considered in the experimental plan. An exoantigen test is also available for the identification of A. *fumigatus.* Other potential human pathogenic fungi also may occur in compost but they are more difficult to isolate and identify. These include the *Rhizomucor pusillus,* which causes infections that have no known cure. Although incorporating assays for these organisms in the experimental design is probably impractical, it would be prudent to at least have the starting material examined by a competent medical mycology laboratory.

Bioindicators

Many fungi could be considered as possible bioindicators in such an experiment. There are microfungi known to be highly tolerant of copper, for example, but it seems likely that direct assays would be more effective means of detecting metals. Ambitious isolation and identification of soil or rhizosphere microfungi is likely to be outside the financial resources of the proposed experiment, and would probably only give marginally useful results. Targeted isolation of specific fungi known to be affected by particular variables that are expected to be important in the experiment could be considered. Calculation of total fungal biomass (inferred from ergosterol assays or other physiological assays) would probably be as detailed as the resources of the proposed experiment could support.

Compost Initiative - Contribution from Biology Resource Division

Henri Goulet, Yves Bousquet, AAFC

Following a brief discussion with invited biologists especially those involved with soil arthropods, I felt that something could be considered with two groups of arthropods: the ground beetles Coleoptera: Carabidae) and soil mites.

Ground beetles consist primarily of general predators and scavengers. They are at the upper end of the food chain in the insect world. Ground beetles are ideal as bio-indicator agents. First, their taxonomy or species definition is basically complete for all regions of Canada. Second, the diversity of species is impressive: over 900 species recorded from Canada. Third, the range of each species is generally well defined. Fourth, the habitat requirements of most species is well understood - in other words we know if a species is normal or accidental to a given environment. Fifth, we know about the general biology of about half of its species (life cycler immature stages). Sixth, the adult stage for most species is exceptionally very long: from one to several years. Both Drs. Yves Bousquet and myself are knowledgeable about this insect family which is well represented in all agricultural regions of Canada.

Soil mites are the main arthropod component in the soil and are very significant in the composting process as well as in any rich organic substrates. We have expertise, Drs. I. Smith, V. Behan-Peletier and E. Lindquist, who would be interested in contributing in the above project based on several mite groups where taxonomic knowledge is generally under control. Because of my limited knowledge of these arthropods, I cannot bring all their significant points as bio-indicators.

There is no doubt in my mind that they might have more to offer than ground beetles because of their incredible abundance and diversity in these habitats.

In my opinion, two variables are significant in this project: the species diversity and density per unit area. To do a comparative analysis, we need both a control and an experimental area in each region. Because our work is taxonomy, we feel that an ecologist is needed in designing a sampling program for these insects and mites, and to analyse statistically the results derived from our identifications. The ecologist should closely interact with the taxonomists in planning the sampling program of the research plots. In addition, technical help is needed for the preparation of specimens to facilitate identification of those not easily recognized in preservative.

National Agricultural Compost Trial - Municipal and Industrial Solid Waste Compost

Dr. Frank Marks, Director, PMRC
Pest Management Research Centre, AAFC, London

The proposed project is of interest to us at PMRC as it fits with research underway through Green Plan on utilization of manure and urban organic waste as soil amendments. As well, the project is of interest as it relates to water quality and agricultural activities under GLS000 and COA (re water quality in the Great Lakes Basin). A particular area of interest to us for this project however is the ancillary benefits that may accrue from the use of such soil amendments re soil structure, soil biology, and biocontrol of soilborne diseases.

PMRC supports this initiative by CLBRR to enhance the scientific basis of such trials and contribute to coordination, research and reporting of the soil and environmental risks associated with such soil amendments. We envision PMRC's role to be complimentary to that of CLBRR by helping to determine the benefits of municipal and industrial composts, either alone or in combination with other organic 'wastes, soil and water quality, impacts on soil ecology and the enhancement of natural controls of plant pathogens. The pressure to use soil as a medium for disposal of organic and industrial garbage will increase greatly. We believe it is incumbent upon AAFC to help ensure that agricultural land is protected from contaminants which might; render that resource unsuitable for the production of safe food; result in adverse effects on soil quality that may increase production costs and result in reduced competitiveness; or result in adverse off-site impacts on water quality. This will require the effective coordination of expertise within the Branch. If we do it right, we can help make both the farmers and the garbage people winners. However, time is short and effective, concerted, and coordinated action will be required.

APPENDIX 3 RESEARCH PROPOSALS

A limited number of research proposals were submitted. It is likely that a leadership role for the CCC would be required to encourage interested parties to come forward and declare their interest. It was our perception that several interested parties were reluctant to present their proposals until they were more confident that the NACT would be a reality. It is the recommendation that another call for proposals take place. We suggest that the CCC prepare and distribute a formally announced call for proposals. In this regard we are only providing the title, collaborators and objective of submitted research proposals in this document. For specific other information please call the proposer or Sherman Nelson (613) 759-1901.

Proposer and collaborators	Title	Objective
G. Neilsen, AAFC, Summerland, B.C.	Composted source-separated and high quality wastes: British Columbia Regional Trials	To demonstrate improvements in quality of sandy soil and growth, yield and health of high value crops resulting from compost application.
Frank Larney, AAFC, Lethbridge T. Clark, Olds College J.J. Leonard, UniVersity of Alberta M.A. Arshad, AAFC, Beaverlodge C. Chang, AAFC, Lethbridge H.H. Janzen, AAFC, Lethbridge R.A. Janzen, University of Alberta.	Composted source-separated solid waste agricultural trials	To assess the soil and environmental changes associated with composted CSSSW application and its agronomic benefits as an amendment for agricultural soils.
Loraine Bailey, Research Scientist, Brandon Research Centre, AAFC; Greg Holden, Clear Lake Golf Foundation Inc., Wasagaming; and Daryl McCartney, P.Eng., University of Manitoba.	The National Compost Program - National Agricultural Compost Trials Manitoba Partners	To study the use of category A compost at the most highly visible location in rural Manitoba, the Clear Lake Golf Course located in Riding Mountain National Park.
J. Gaynor, C. Tan, C. Drury and R. Garton, AAFC, Harrow and Industry partners: Paul van der Werf (Green Lane Environ.), Vegetable Growers Marketing Board. Municipal partners: Cameron Wright (Essex Windsor Waste Management).	Proposal for CSSSW	To assess the suitability of composted source-separated solid waste for processing tomato production on sandy soil in southwestern Ontario.
S. Nelson and H. Dinel, CLBRR, AAFC, Ottawa; Manderley Sod, CORCAN.	Technology for the use of source-separated solid waste compost as a soil amendment and in artificial growing medium	To develop technology for the use of source-separated solid wastes as a substitute for peat and topsoil in the nursery, sod and greenhouse industries.
H.Dinel, M. Schnitzer, D. Gamble, S. Nelson, CLBRR, AAFC, Ottawa.	Assessment of the nature and reactivity of organic matter during and after composting	To assess changes in the chemical and biological reactivity of organic matter during and after composting.

Proposer and collaborators	Title	Objective
J. MacLeod et al., AAFC, Charlottetown	Composted municipal solid waste as an amendment for soils in potato rotations	To determine the benefits of using composted MSW in improving chemical, physical and biological properties of soils and crop productivity in potato rotations
J. Richards, AAFC, Fredericton; C. Bourque, University of Moncton	A study to investigate the benefits of applying compost to soils cropped to potatoes	To determine the amount of SSMC needed to increase the net profitability realized from potato production
V. Rodd, K. Webb, S. Gaul, P. Hickleton, A. Jamesion, AAFC Nappan, Truro and Kentville N.S.; P. Warman NSAC, Truro, and R. Halsey, Acres Int. Halifax.	Evaluation of compost as a fertilizer source and soil amendment in Nova Scotia	To compare source-separated municipal compost and soild manure with and without fertilizer. To determine the effect of source-separated MSW compost on vegetable crop production and soil properties. To compare source-separated MSW compost, wood chips, and living mulches to improve field colonization by lowbush blueberry. To assess source-separated MSW compost as a peat substitute in the nursery production of small fruit and other crops in containers.

APPENDIX A COMPOSTING OPERATIONS IN ONTARIO

Names and Capacity of Composting Operations in Ontario (recompiled based on the Composting Council of Canada, 1993)

Map Labels	Community/Company (Figure3)	Location	Capacity (t/yr) (Approximate)
1	All Treat Farms	Arthur	not listed
2	Tony Recycling	Aylmer West	27000
3	City of Barrie	Barrie	300-400
4	Sweda Farm	Blackstock	72000
5	City of Brampton	Brampton	1000-2500
6	City of Brantford	Brantford	2500-7000
7	City of Brockville	Brockville	1000
8	Original Vermi Composter	Brockville	8-66
9	City of Burlington	Burlington	2300
10	City of Chatham	Chatham	not listed
11	Northumberland County	Cobourg	2400
12	Mammone Disposal	Concord Point	30000
13	Mun. of Cornwall	Cornwall	500
14	Mun. of Dryden	Dryden	200
15	Metro Toronto	Etobicoke	7000
16	Mun. of Fort Erie	Fort Erie	300-325
17	City of Guelph	Guelph	2000
18	Univ. of Guelph	Guelph	5000
19	R.M.of Ottawa-Carleton	Kanata	450
20	CORCAN	Kingston	440-5000
21	City of Kingston	Kingston	3000
22	Original Vermi Composter	Kingston	8-66
23	CORCAN	Kingston	12000-50000
24	City of Pittsburgh	Kingston	500
25	Sant & Sons Greenhouses	Kleinburg	80
26	Original Vermi Composter	Lindsay	8-66
27	Original Vermi Composter	London	8-66
28	Int. Process Systems	London	60000
29	Simcoe County	Midhurst	1000
30	Scott Farms	Milton	10000
31	City of Mississauga	Mississauga	1070
32	CORCAN	Muskoka	not listed
33	Canada Composting Inc.	Newmarket	70000
34	York Region	Newmarket	50000
35	Grow-Rich Inc.	Niagara Falls	70000-100000
36	City of Niagara Falls	Niagara Falls	200
37	City of North York	North York	15000
38	Halton Region	Oakville	12500
39	City of Oakville	Oakville	not listed
40	City Of Orillia	Orillia	1600
41	City of Parkhill	Parkhill	not listed
42	City of Pembroke	Pembroke	120
43	City of Peterborough	Peterborough	2000
44	City of Port Colborne	Port Colborne	not listed
45	Ottawa-Carleton Region	Richmond	7180
46	City of Sarnia	Sarnia	2000
47	City of Sault Ste. Marie	Sault Ste. Marie	1100
48	City of Scarborough	Scarborough	12000
49	Toronto Zoo	Scarborough	10-40

50	City of Smiths Falls	Smiths Falls	1300
51	Original Vermi Composter	Toronto	8-66
52	Ontario Science Centre	Toronto	250
53	Metro Toronto	Toronto	35000
54	City of Hensall	Walton	9000
55	Waterdown Gardens	Waterdown North	19000
56	Waterloo Region	Waterloo	4400
57	Durham Region	Whitby	8000
58	Essex County	Windsor	550
59	City of Windsor	Windsor	600
60	City of Woodstock	Woodstock	not listed