Congratulations are extended to Morwick Scholarship recipients Gene Shelp and Derek Veenhof by Jean Smith, daughter of Professor Frank Morwick.
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FOREWORD

The Annual Report provides a glimpse of the exciting developments in teaching, research and extension which have occurred in the Department of Land Resource Science in the past year.

The developments are consistent with the following statement which has been crafted to reflect the mission of the Department:

The Department is striving to create an environment for the study of land resources which:

(a) integrates superior educational programs with innovative research programs utilizing state of the art facilities and

(b) ranks among the top five institutions in the world with a similar mandate.

The Department will:

- focus on integration of studies of the lithosphere, pedosphere, hydrosphere, biosphere and atmosphere with a view to the sustainable development of renewable resources
- maintain a research program which represents a continuum in scale from microscopic to regional/national, retains a balance between research needed to address specific societal needs and the needs for an improved understanding of land resources, and addresses a range of resource uses while retaining the principal emphasis on agricultural use of land resources
- maintain a coherent continuum of educational programs including correspondence courses in public awareness initiatives, diploma level courses, bachelor level courses (offered on campus and through Distance Education) and majors, Master’s and Ph.D. degree programs, Continuing Education (Professional Development) and technology transfer
- maintain a strong commitment to service to professions, government bodies and industries related to the use of land resources and in particular the agrifood industry
- recruit superior students, faculty and staff and provide enhanced opportunities for their professional development.

Undergraduate and graduate programs related to land resources have undergone considerable restructuring in the last five years in order to more effectively equip our graduates to meet the challenges of the next century. Undergraduate majors such as Soil Science, Earth Science, and Resources Management have evolved into a new suite of majors focusing on agriculture in the B.Sc.- (Agr.) program (Agronomy, Natural Resources Management) and on environmental issues in the B.Sc.(Env.) program (Earth and Atmosphere Sciences, Natural Resources Management). The two graduate programs (Soil Science and Agricultural Meteorology) have evolved into a single new graduate program (Land and Atmosphere Sciences) with fields of study in Atmosphere Science, Soil Science, Environmental Geology and Land Resources Management.

Research programs have continued to grow with the greatest growth in studies related to diminishing soil degradation and improving air and water quality in agricultural areas.

Extension efforts continue to grow as the Department makes a concerted effort not only to get the latest research findings out to the different user groups, but also to continue to receive advice and comments on emerging research needs. Highlighting extension activities in the past year has seen effort directed to enhancing the efficiency of nitrogen use on Ontario farms and diminishing the extent of groundwater contamination. The extension effort arises from a research-demonstration project called the "Partners in Nitrogen Project" which was designed to assess the economic and environmentally acceptable rates of nitrogen application under field scale conditions on a range of soils used for corn production across the province. A recent survey of the quality of groundwater in rural areas (which faculty from Land Resource Science participated in) has provided additional incentive to enhance the efficiency of nitrogen use.

The success that we have achieved in the past year is a reflection, in part, of the enthusiasm and creativity of students, staff, and faculty in the Department. The skills and the attitudes that enable members of the Department to fulfill their roles are, however, strengthened by the moral and financial support and the constructive criticism that a much larger community provides to the Department. This report is really dedicated to you as a member of that larger community. We value your involvement in our programs and we look forward to continued exchange with you.

In closing I wish to acknowledge the effort of S. Bushen, D. Irvine and V. Rasiah in assembling this report and in encouraging all of us to meet publication deadlines.

B.D. KAY
Professor & Chair

1
PERSONNEL AND INTERESTS
FACULTY/PROFESSIONAL STAFF

B.D. KAY, B.S.A., M.Sc. (Guelph), Ph.D. (Purdue), Professor and Chairman. Physical-chemical reactions in soils, dynamics of frost heaving, influence of tillage and cropping practices on soil structure. (Ext. 2447-8)*.


E.G. BEAUCHAMP, B.Sc.(Agr.), M.Sc. (McGill), Ph.D. (Cornell), Professor. Nitrogen in the soil/crop system; manures; fertilizers and plant nutrition. (Ext. 3239).

M.E. BROOKFIELD, B.Sc. (Edinburgh), Ph.D. (Reading), Associate Professor. Paleoecology, paleontology, stratigraphy and tectonics. (Ext. 2654).


W. CHESWORTH, B.Sc., M.Sc. (Manchester), Ph.D. (McMaster), Professor. Geochemistry, petrology, mineralogy, geological mapping. (Ext. 2457).

D.E. ELRICK, B.S.A. (Toronto), M.S., Ph.D. (Wisconsin), Professor. Soil physics; solute and water transport in soils. (Ext. 3758).

L.J. EVANS, B.Sc. (Southampton), Ph.D. (Wales), Professor. Soil chemistry and clay mineralogy. (Ext. 3017).

G. FAIRCILD, B.Sc., M.Sc. (McGill), Ph.D. (Guelph), Post-Doctoral Fellow. Variable application technology for increased fertilizer use efficiency and environmental protection. (Ext. 2450).

C.A. FITZGIBBON, B.A. (McMaster), M.Sc. (Saskatchewan), Teaching Associate and Co-ordinator of Landscape Architecture Computer Laboratory. Soil science, resources planning and management. (Ext. 4802).

M.J. GOSS, B.Sc. (London), M.Sc. (Birmingham), Ph.D. (Reading), Professor and Chair, Land Stewardship. Impact of current agricultural practices on soil and water resources. Soil-root-shoot relations. (Ext. 2491).

T.J. GILLESPIE, B.Sc. (British Columbia), M.S.A. (Toronto), Ph.D. (Guelph), Professor. Relationship of plant diseases and pests to weather; computer modelling of soil and air microclimates. (Ext. 2645).

P.H. GROENEVELT, M.Sc., Ph.D. ( Wageningen), Professor. Soil physics, soil and water conservation and land reclamation. (Ext. 3585).

S.G. HILTS, B.A. (Western Ontario), M.A. (Toronto), Ph.D. (Toronto), Director, Centre for Land and Water Stewardship; Associate Professor. Joint appointment with University School of Rural Planning and Development. Natural resources management, environmental planning, land stewardship. (Ext. 2702).

R.G. KACHANOSKI, B.Sc., M.Sc. (Saskatchewan), Ph.D. (California, Davis), Associate Professor and Co-ordinator of Extension. Soil physics, soil and water conservation and extension. (Ext. 2498).

G.E. KIDD, B.A.Sc., M.A.Sc. (Waterloo), Professional. Electronic instrument development; transport processes within and above plant canopies. (Ext. 3434).


I.P. MARTINI, Doct. Geol. Sci. (Florence), Ph.D. (McMaster), Professor. Sediments and sedimentary rocks, sedimentology, glacial geology. (Ext. 2488).

R. MCBRIDE, B.Sc., Ph.D. (Guelph), Associate Professor. Soil science and agricultural land use planning. (Ext. 2492).
T.P. MCgonigle, B.Sc. (Sussex), D.Phil. (York), Scientist. Vesicular-arbuscular mycorrhizas and their effect on plant growth. (Ext. 8748).

M.H. Miller, B.S.A. (Toronto), M.S., Ph.D. (Purdue), Professor. Soil fertility and plant nutrition. Mycorrhizal relations. Integrated farming systems research. (Ext. 2482).


E. Perfect, B.Sc. (Newcastle-upon-Tyne), M.A. (Carleton), Ph.D. (Cornell), Scientist. Effect of cropping systems and ground freezing on soil structure. (Ext. 4276).

R. Protz, B.S.A., M.S. (Saskatchewan), Ph.D. (Iowa State), Professor. Soil genesis and classification; soil variability; soil clay mineralogy; mapping techniques and soil landform relationships. (Ext. 2481).

V. Rasiah, B.Sc. (Ceylon), M.Sc., Ph.D. (SDSU), Scientist. Land stewardship cropping systems. (Ext. 3393/8166).


R.L. Thomas, B.Sc., M.Sc. (Alberta), Ph.D. (Ohio State), Professor. The chemical characterization and reactions of soil organic matter. (Ext. 2459).


D. Trivers, B.Sc.(Eng.) (Guelph), Systems Engineer. Ontario Ministry of Agriculture and Food, Agroclimatological Program. (Ext. 2480).

H.P. Van Straaten, Dipl. Geol., Dr. rer. nat (Göttingen, Germany), Scientist. Geology, mineral exploration, agrogeology in East Africa. (Ext. 2454).

R.P. Voroney, B.Sc. (Calgary), M.Sc., Ph.D. (Saskatchewan), Associate Professor. Soil biological activity, soil management. (Ext. 3057).

G.J. Wall, B.Sc.(Agr.), M.Sc. (Guelph), Ph.D. (Ohio). Agriculture Canada, Associate Graduate Faculty. (Ext. 2103).

*Extension number (e.g. Ext. 2447) at the University of Guelph. University of Guelph phone number is (519) 824-4120.

FAX No. (519) 824-5730

CLERICAL/TECHNICAL STAFF


P.E. Beirnes, Administrative Secretary. (Ext. 2448).

D. Bergstrom, B.Sc. M.Sc. (Alberta), Ph.D. (Guelph), Research Associate. (Ext. 8593).

L. Biswell, Clerk. (Ext. 4359).

D. Brenner, Secretary. Extension. (Ext. 6364).

S. Bushen, Secretary. (Ext. 6365).

M. Cochrane, Secretary. Soil and Water Conservation Information Bureau. (Ext. 2799).


E.F. Gagnon, Assoc. Dipl. Agr. (Guelph), Manager. Analytical Services Laboratory. (Ext. 2494).

B. Grant, B.Sc.(Guelph), Research Assistant. Measurement of nutrient transport and agricultural pesticides from cropland.

K. Howe, B.Sc.(Agr.) (Guelph), Research Assistant. Soil compaction. (Ext. 4265).


L. LIU, B.Sc. Agr. (Hubei, China), M.Sc. (Guelph), Ph.D. candidate (Guelph), Research Associate. Amelioration of acid mine drainage project. (Ext. 2450).

V. MARCILLE-KERSLAKE, B.Sc., M.Sc. (Guelph), Assistant Manager, Analytical Services Laboratory. (Ext. 2494).


H. MCNAIRN, BES (Waterloo), M.Sc. (Guelph). Research Associate. Image analysis and remote sensing lab. (Ext. 4274).


J.A. POISSON, B.Sc. (Guelph), Technician. Soil chemistry/biochemistry and Analytical Services Laboratory. (Ext. 2494).

P.J. ROBERTS, Secretary. Undergraduate and graduate programs. (Ext. 2456).

S. SADURA, B.Sc. Agr. (Guelph), Teaching and laboratory technician. Information technology. (Ext. 3393).

J.K. SCARROW, Clerk. (Ext. 2455/2661).


P. SMITH, B.A. (Guelph), Technician. Land Stewardship. (Ext. 4263).


M. VEEHOF, Research Assistant. Agroforestry. (Ext. 3488).


C. WAGNER-RIDDLE, B.Sc. Agr. (Brazil), M.Sc. (Brazil), Ph.D. (Guelph), Research Associate. Agrometeorology; crop modelling; emission of trace gases from agricultural fields. (Ext. 2787).

W.G. WILSON, B.Sc. (Guelph), Technician. Soil chemistry, biology and clay mineralogy. (Ext. 8157).


Z. ZHANG, Ph.D. (Guelph), Post-Doctoral Research Associate. Soil biology. Commenced duties at Anhui Institute of Environmental Studies, P.R.C., January 1993.


S. ZHOU, B.Sc. (Shenyang), M.Sc. (Wageningen), Research Assistant. Non-limiting water range. (Ext. 8160).

*Extension number (e.g. Ext. 2447) at the University of Guelph. University of Guelph phone number is (519) 824-4120.

FAX No. (519) 824-5730
UNDERGRADUATE EDUCATION

R. Proetz

Enrolment in nearly all undergraduate courses has increased over the last year. We are currently enrolling students into the new B.Sc. Majors; 1) Natural Resources Management and 2) Earth and Atmosphere Science. At the same time we are re-assessing the B.Sc.(Agr.) Core courses and Majors. This re-assessment process has been going on for the last several months and will be completed by February, 1994. Going through this re-assessment process should result in a re-invigorated faculty, offering the 1999 B.Sc.(Agr.) graduate the information content and honing the skills they will require to establish a profitable, sustainable and environmentally astute agri-food system.
## UNDERGRADUATE EDUCATION

UNDERGRADUATE DIPLOMA AND DEGREE COURSES OFFERED DURING 1992

<table>
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<td>Paul Chisholm</td>
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<td>Ramadhan Ngatoluwa</td>
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AGRONOMY MAJORS

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<tr>
<td>Dennis Joosse</td>
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UNDERGRADUATE IN-COURSE AWARDS

November 1992

John A. Archibald Memorial Scholarship
Peter Chesney
Soil Science

Robert Harcourt Scholarships
Adriana Perkins
Resources Management

Robert McCann Scholarship
Jackie Fraser
Resources Management

Foodland Hydro Scholarship
Bronwynne Wilton
Resources Management

Thomas H. Peters Scholarship
Lynn Rowan
Resources Management
DEAN'S HONOURS RECIPIENTS

F'92
Lori Armstrong
Andrew Batchelor
Phillipa Evert
Jackie Fraser
Heather Kepran
Jon Gingerich
Bubby Kettlewell
Stephen Litke
Aynslee Ogden
Adriana Perkins
Peter Presant
Lynn Rowan
Lesley Shaffer
Debra Tallan
Tim Bohn

Resources Management
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W'92
Jonathan Clayton
Jackie Fraser
Stephan Fraser
Jeremy Higham
David Jones
Pamela Joosse
Bubby Kettlewell
Tracy Lawrence
Brian Odell
Peter Presant
Fred Probst
Lynn Rowan
Sandra Shore
Stephen Stenabaugh
Patricia Story
Debra Tallan
Angela Tollan
Neil Turner

Resources Management
Resources Management
Environmental Soil Science
Resources Management
Resources Management
Resources Management
Resources Management
Earth Science
Earth Science
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
GRADUATE EDUCATION

In 1992 the Department of Land Resource Science offered a wide range of opportunities for graduate studies at the M.Sc. and Ph.D. levels. M.Sc. programs were available in Agrometeorology, Soil Science, and in Resources Development (in conjunction with the University School of Rural Planning and Development). Ph.D. programs were available in Agrometeorology and Soil Science. The Department also participated in the interdepartmental groups on Biophysics, Plant Physiology, and Toxicology whereby a student registered in the Department may enrol and specialize in one of the disciplines. Beginning in 1993-94, the various graduate programs offered by the Department will be consolidated into one graduate program in Land and Atmospheric Science. The four fields of study comprise: (1) Atmospheric Science (2) Soil Science (3) Environmental Earth Science and (4) Land Resources Management. The cross-disciplinary nature of the new program with its strengths in four fields and emphasis on integration of these disciplines is unique in Canada.

Financial assistance in the form of scholarships, research assistantships, and teaching assistantships are available to qualified students. Research facilities available include well equipped laboratories for agrometeorology, soil chemistry, soil mineralogy, soil physics, soil biology and biochemistry, and plant nutrition. Research instrumentation includes x-ray diffraction, mass spectrometry, liquid and gas chromatographs, an Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES), sonic anemometry, gas analyzers, data loggers, and agrometeorological field equipment. Greenhouses, growth chambers and 50 ha of field research plots are available for research projects. A graduate student has the opportunity to work with faculty in one of the many research projects underway in the Department. For further information contact the faculty members in the relevant area of interest or the Graduate Co-ordinators in Agrometeorology or Soil Science.

Graduate Co-ordinators:
Agrometeorology - G.W. Thurtell
Soil Science - R.L. Thomas
Land and Atmospheric Science - D.E. Elrick (beginning Fall'93)

GRADUATE STUDENTS AND ADVISORS - WINTER SEMESTER, 1993

AGROMETEOROLOGY

M.Sc. Students
Admiral, Stuart
Lin, Mei
Lyamchay, Charles
Popa, Romeo
Simpson, Isobel

Ph.D. Students
Gordon, Robert
Lin, Shaojun

Advisors
G.W. Thurtell
G.W. Thurtell
T.J. Gillespie
Thurtell/King
G.W. Thurtell
D.M. Brown
T.J. Gillespie
## SOIL SCIENCE PROGRAM

### M.Sc. Students

<table>
<thead>
<tr>
<th>Name</th>
<th>M.Sc. Student</th>
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<tbody>
<tr>
<td>Covert, Jeff</td>
<td>E.G. Beauchamp</td>
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<td>Eshraghi, Navi</td>
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### Ph.D. Students

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<td>Addy, Heather</td>
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<table>
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<tr>
<th>Student</th>
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<tbody>
<tr>
<td>Zhang, Zhiyuan</td>
<td>Ph.D.</td>
<td>P. Voroney</td>
<td>Role of Collembola in Organic Matter Decomposition in Soil</td>
<td>March 16, 1992</td>
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<td>Lu, Shen</td>
<td>Ph.D.</td>
<td>M.H. Miller</td>
<td>Efficiency of phosphorus placement and its effect on VA mycorrhizal development in field-grown maize (Zea mays L.) in early growth stages.</td>
<td>May 27, 1992</td>
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<td>van der Werf, Paul</td>
<td>M.Sc.</td>
<td>T.E. Bates</td>
<td>The Effects of Various Composts on Established Turf Grass</td>
<td>April 9, 1992</td>
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<td>Rombang, Johan</td>
<td>M.Sc.</td>
<td>P.H. Groenevelt</td>
<td>The Role of Clay Mineralogy in Aggregate Stability and a SEM Study of Bonds in Soil Aggregates</td>
<td>August 4, 1992</td>
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<td>Bergstrom, David W.</td>
<td>Ph.D.</td>
<td>E.G. Beauchamp</td>
<td>Relationships between denitrification rate, denitrifying enzyme activity and predictive soil properties.</td>
<td>August 20, 1992</td>
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<td>Olaku, Hillary</td>
<td>M.Sc.</td>
<td>L.J. Evans</td>
<td>Molybdenum Retention by Kenyan Soils</td>
<td>November 19, 1992</td>
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### Agrometeorology

<table>
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<tr>
<td>Fuentes, Jose</td>
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<td>Effect of Foliage Surface Wetness on the Deposition of Ozone.</td>
<td>April 15, 1992</td>
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<td>Wagner-Riddle, Claudia</td>
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<td>The Effect of Rye Mulch on Soybean Yield: A Field and Modelling Study.</td>
<td>May 11, 1992</td>
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<td>Wang, Xiaolong</td>
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<td>T.J. Gillespie</td>
<td>Simulation of Leaf Surface Wetness Effects on Radar Backscatter Using the MIMICS Model</td>
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GRADUATE EDUCATION
GRADUATE DEGREE COURSES OFFERED DURING 1992

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<td>87-601</td>
<td>Soil Genesis and Classification</td>
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<td>Soil Organic Matter &amp; Biochemistry</td>
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<td>Analytical Instrumentation &amp; Techniques</td>
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<td>87-655</td>
<td>Principles of Scientific Research</td>
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<td>87-665</td>
<td>Special Topics in Land Use</td>
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<td>87-675</td>
<td>Seminar</td>
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GRADUATE AWARDS NOVEMBER 1992

Soden Fellowship in Agriculture
Isobel Simpson
Romeo Popa

Mary Edmunds Williams Fellowship
Heather Addy
Anderson Ward

Commonwealth Scholarship
Sudas Wanniarachchi

Natural Science and Engineering Research Council Fellowship
Heather Addy
Robert Gordon
Isobel Simpson
Stephen Fraser

University of Guelph Graduate Fellowship (Department)
Alvaro Da Silva
Jackson Langat

Visa Scholarship
Mei Lin (F’91)
Shaojun Lin

CIDA Scholarship
Elizabeth Gachuiri
Jacinta Kimiti
Jackson Langat
Mei Lin

IDRC Scholarship
Anton Dey

Ontario Differential Tuition Waiver Award
Zhiyuan Zhang
Xiaolong Wang
Romeo Popa

World University Service of Canada
Anna Maria Makalew

Morwick Scholarship
Gene Shelp
Derek Veenhof

Franklin Graduate Scholarship
Gene Shelp
Derek Veenhof

Waterdown Garden Supplies Graduate Scholarship
David Raymond

N.R. Richards Scholarship
Pamela Joosse
EXTENSION HIGHLIGHTS

Extension and outreach activities are a high priority for the Department of Land Resource Science. Total activities accounted for 1.5 years of faculty time. The outreach program continues to be carried out in close cooperation with a number of farmer groups, Ontario Ministry of Agriculture and Food (OMAF), and industry. The extension program in the department is coordinated by Dr. Gary Kachanoski, who was the recipient of the 1992 Distinguished Extension Award from the Ontario Agriculture College Alumni Association.

A significant amount of time was spent dealing with agriculture and the environment, particularly surface water and groundwater quality. The emphasis on groundwater coincides with the release of the Farm Groundwater Quality Survey carried out jointly by the Dept. of Land Resource Science (through the Centre for Soil and Water Conservation), University of Waterloo’s Centre for Groundwater Research, the Ontario Soil and Crop Improvement Assoc., and government ministries of Agriculture, Environment, and Health. The survey resulted in numerous requests for talks, information, news and television interviews related to agriculture and water quality. A special edition of the Soil and Water Conservation Information Bureau’s newsletter (InfoSource) was sent out. Faculty in the Department helped plan and review the newsletter. A special session on the groundwater survey, along with information on nutrient management was organized for the 1993 OAC days.

The Department has targeted nitrogen management related to water quality and economic returns in its outreach program for the past three years, and the activity continued in 1992. The release of the new nitrogen soil test and the need to explain its benefits and use in optimizing N fertilizer use was also an area of high priority for outreach activities. An "Update on the N soil test" was written and published in 1992. The provincial Partners-In-Nitrogen (PINS) project continued for its final year in 1992. The project is a cooperative effort with the Fertilizer Institute of Ontario, OMAF, and Ontario farmers. The project helped to develop and test the nitrogen soil test and examine the relationship between environmentally acceptable and economical rates of nitrogen fertilizer application on corn.

The final report of the 5 year Tillage-2000 program was completed and is in-press. The report completes the successful demonstration/research project which involved up to 40 farm cooperators, 30 OMAF field staff, and a number of researchers. The project demonstrated the environmental and economical benefits to adopting a conservation tillage system in Ontario.

Provincial expert committees continue to occupy a significant portion of faculty extension time. Expert advice related to all aspects of soil, climate, and management are needed on these type of committees, and their decisions can affect rural land use for years to come. The Ontario Soil Management Research and Services Committee and the Sludge and Waste Utilization Committee are two of these important committees.

The Department is continuing its commitment to promoting efficient nutrient use in agriculture. In 1992, the Departments' Analytical Services Laboratory became an accredited soil testing lab under the OMAF provincial accreditation program. The lab offers a complete soil testing and fertilizer recommendation program for Ontario farmers.
RESEARCH SUMMARY

Research involves learning about ourselves and our environment. It provides new information as a cornerstone for teaching in a University and for society in general. Although curiosity is often the driving force for the research we do, our objectives and goals are usually mission-oriented. Our research generates new knowledge and new ideas which will assist those needing to know more about our land resources and our ability to sustain them for the future.

The total value of grants and contracts supporting research in Land Resource Science in 1992 was approximately $3.58 million. This amount represents a further significant increase over last year. The Ontario Ministry of Agriculture and Food contributed $1.26 million to this funding. Other agencies which contributed funding to Land Resource Science include the following.

- Natural Sciences and Engineering Research Council
- Agriculture Canada
- Canadian International Development Agency
- Potash-Phosphate Institute of Canada
- Ontario Heritage Foundation
- Ontario Ministry of Agriculture and Food (special projects)
- Environment Canada
- The Fertilizer Institute of Ontario Inc.
- Ontario Ministry of the Environment
- Ontario Turfgrass Research Foundation
- Employment and Immigration Canada
- University Research Incentive Fund (Ontario Government)
- Deluxe Paper Products Ltd.
- Lily Cups Inc.
- IG International Wastes
- Inco Ltd.
- Dofasco Inc.
- Tetapaga Mining Co. Ltd.
- Wildlife Habitat Canada
- Forestry Canada
- Metropolitan Toronto

The funding from these agencies indicates the continuing and increasing needs for more knowledge about our land resources. In addition, the funding helps to maintain a dynamic research program at the frontiers of new knowledge.

Progress reports on research projects in 1992 are presented in the following pages. An index of authors are presented at the end of this Report. The reports are grouped as follows:

1. Land characterization
2. Land management
3. Land inventory and stewardship
### CURRENT RESEARCH PROJECTS AND FUNDING SOURCES

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<tr>
<th>Faculty</th>
<th>Title of Project</th>
<th>Funding Agency</th>
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<tbody>
<tr>
<td>Beuchamp, E.G.</td>
<td>N₂O Emissions in Intensive Crop Production Systems</td>
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<td>Voroney, R.P.</td>
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<td>Denitrification in Soils</td>
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<td>Nitrate Supply from Manure</td>
<td>O.M.A.F.</td>
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<td>Brookfield, M.E.</td>
<td>Orogenesis and Basin Development</td>
<td>N.S.E.R.C.</td>
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<td>Brown, D.M.</td>
<td>Forage Quality as Affected by Atmospheric Drying Conditions and Rainfall</td>
<td>O.M.A.F.</td>
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<td>Geochemistry of Soil Formation</td>
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<td>The Utilization of Natural Organic Materials in Amelioration of Acid Mine Drainage</td>
<td>University of Guelph Research Excellence Fund</td>
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<td>Mine Drainage Associated with Sulphide Rich Tailings</td>
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Evans, L.       Metal Retention by Soils                      N.S.E.R.C.
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Gillespie, T.J.  Microclimate Mapping                       Ontario Turfgrass
Gillespie, T.J.  Leaf Surface Wetness on Ozone              Research Foundation
Goss, M.J.       Manure Management to Sustain                Agriculture Canada
                 Water Quality
Goss, M.J.       Literature Search on Manure Nutrient       Agriculture Canada
                 Management
Hilts, S.G.      Transferring Conservation Technology       Agriculture Canada
                 to Ontario Farms
Hilts, S.G.      Sustaining Stewardship on the               Ontario Heritage Foundation
                 Niagara Escarpment
Kachanoski, R.G. Tillage Effects on Transport               N.S.E.R.C.
                 Processes in Soils
Kachanoski, R.G. Variable Fertilizer Application           Fertilizer Institute
                 N.S.E.R.C.
                 Agriculture Canada
Kachanoski, R.G. Landscape Position                          Agriculture Canada
Kachanoski, R.G. Impact of Livestock Manure and Fertilizer O.M.E.
                 Application on Nitrate Contamination of
                 Ground Water
Kachanoski, R.G. Field Scale Fertilizer                      Potash and Phosphate Institute
Kay, B.D.        Methodologies for Assessing Soil           Agriculture Canada
                 Structure
Kay, B.D.        Soil Stewardship Cropping                    O.M.A.F.
                 E.Y.C.P.
Kay, B.D.        Measurement of Nutrient Transport and      Agriculture Canada
                 Agricultural Pesticides from Cropland
Kay, B.D.        Challenge '92                                  Employment and Immigration
Kay, B.D.        Role of Environmental Factors               N.S.E.R.C.
                 in Land Management
King, K.M.       Atmosphere-Surface Interactions              N.S.E.R.C.
King, K.M.       Surface-Atmosphere Exchange                  N.S.E.R.C.
<table>
<thead>
<tr>
<th>Authors</th>
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<th>Institution</th>
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<tr>
<td>King, K.M.</td>
<td>Surface-Atmosphere Exchange of Greenhouse Gases</td>
<td>Environment Canada</td>
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<td>Martini, P.I.</td>
<td>Sedimentological and Land Use</td>
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Characterization
AN IMAGE ANALYSIS SYSTEM FOR STUDIES OF SOIL PROCESSES


At Guelph we have connected our Array Scanner and the Micro-PIXE facility to our Image Analysis Laboratory by Ethernet. As large arrays of data can rapidly be accumulated we have installed an Optical Disk (WORM) system with a capacity of 850 Megabytes per disk and a Digital Tape Drive with a capacity of 2.3 Gigabytes/tape. Our main processing CPU is a UNIX based Silicon Graphics 4D/35 with a 1.3 Gigabyte hard disk. Therefore, we now can collect spectral data with the Array Scanner and elemental concentrations with the Micro-PIXE facility rapidly and transport it to our laboratory via Ethernet for analyses within EASI/PACE software (PCI Incorporated, 1989).

The use of Micro-PIXE data within Image Analysis software to differentiate pedological features (in the first instance, earthworm transport of trace metals contained in sewage sludge) has been shown by Protz, Teesdale, Maxwell, Campbell and Duke, (1992) and Tomlin, Protz, McCabe, Martin and Legace, (1993).

Work is continuing on the 'automation' of the computer processing of the large spectral and chemical data sets. These efforts are focused on the arrangement of analytical routines within EASI/PACE software to: 1) systematically reduce rasterized Micro-PIXE elemental data for more rapid evaluation of spatial distribution of elements and thus more quickly identify pedological processes, and 2) use Unsupervised Classification routines of spectral (RGB) data of soil thin sections to identify the best spectral data (i.e. reflected, transmitted, polarized and UV reflected) for classification of pedofeatures.

USE OF SATELLITE IMAGERY FOR AGRO-ECOSYSTEM MONITORING


During 1990 the European Space Agency (ESA) launched ERS-1 (Earth Resources Satellite), the payload of which includes a C-Band (5.3 GHz) Synthetic Aperture Radar. The SAR records backscatter from the earth's surface at a 30 metre ground resolution and has an orbital repeat cycle of 35 days. Several Canadian agencies are actively involved in evaluating the data from ERS-1 in preparation for the launch of Canada's radar satellite - Radarsat - in the mid-1990's. The longer wavelengths used in radar remote sensing are essentially unaffected by most atmospheric conditions, allowing for all weather data collection.

The Image Analysis and Remote Sensing Lab is part of a team investigating the relationship between agricultural parameters - crop type and condition, soil moisture and surface roughness - and radar return variation in crop types.
or backscatter. From May to October 1992 crop information was collected at two week intervals over a study area in Norwich Township, Oxford County. Data collection coincided with monthly ERS-1 overflights. The crop information recorded on over 300 fields included crop developmental stage, canopy height, percent ground cover and row direction. As well as spaceborne SAR, airborne SAR, colour infrared photographs, Landsat Thematic Mapper imagery and SPOT imagery was acquired. During the May and October field campaigns, data were gathered on surface soil moisture conditions (bulk density samples and TDR measurements) on 36 fields and surface roughness measurements were made on 17 fields. This research contributes to the overall goal of developing an operational agricultural monitoring system. Such a system, based on imagery acquired from a combination of satellite SAR and electrooptical sensors such as Thematic Mapper and SPOT, could identify crop type and condition and soil moisture conditions within hours or days of a satellite overpass.

Measuring soil roughness.

AN ELECTRON MICRO PROBE AND PIXE STUDY OF EARTHWORM ACTIVITY IN SOIL AMELIORATION

R. Protz\(^1\), D.C. McCabe\(^1\), A.D. Tomlin\(^1\), R.R. Martin\(^3\) and C. Duke\(^1\)

Electron Microprobe (EMP) and Proton Induced X-ray Emission (PIXE) techniques were used to determine in situ elemental concentrations in 5 x 5 micron spots in earthworm excreta and the soil matrix. Concentrations of Ca, Fe and Al, used in three precipiants of separate sewage sludges as well P and the trace metals, Zn, Cr, Pb, Co, Ni and Cd were measured at the 0-5, 10-15 and 40-45 cm depths in three soil profiles. Raster arrays of elemental concentration in 400 x 400 micron areas were also determined by PIXE. These arrays of elemental distributions were analyzed with the aid of EASI/PACE image analysis software to determine the spatial associations of the elements. The results will also be discussed as a means of studying the relationship between spatial soil chemistry and earthworm activity. The variability of elemental distributions and associations within these soils are being used to develop a model of earthworm activity in soil amelioration.

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\(^3\)Chemistry, University of Western Ontario, London, Ontario.
THE USE OF GAMMA ISOTOPES FOR SOIL GENESIS STUDIES


Recently we have published and presented papers on the use of the depth distribution of Cs$^{137}$ as an indicator of soil faunal activity and as a measure of the rates of soil accretion. During the last year we have extended our studies to include a range of Ontario soils, Gleysols and Organics from the James Bay Lowlands, Luvisols from the Lake Erie Watershed, Podzols and Brunisols from the Canadian Shield and Regosols and Brunisols from a dune sequence in the Pinery Park. Results from these measurements indicate that gamma isotopes will be useful for measuring recent (<100 years) pedogenic processes within Ontario soils. Our efforts have been directed towards the rapid processing of the gamma isotope data and the collection of a comprehensive data base on Ontario soils.
MICROMORPHOLOGY AND MICROFACIES OF LOWER CRETACEOUS (ALBIAN) PALEOSOLS, SOUTHWESTERN ALBERTA, CANADA

P. J. McCarthy and I. P. Martini

The objectives of this investigation are to establish the presence, type(s) and degree of development of paleosols in strata of the Lower Cretaceous (Albian) Blairmore Group, southwestern Alberta, and to use the paleosols to enhance the environmental interpretation of these floodplains.

Representative paleosol profiles were selected for detailed petrographic and micromorphological study. Specific paleosol profiles examined include Coleman, Mill Creek Bridge, Highwood Junction, Bruni Creek, Sheep River, Measar Kipp, and Gulf Barons.

Detailed micromorphology has revealed the nature of 8 microfacies containing numerous epigenetic features including root traces, organic fragments, clay coatings and infillings, papules, iron, and manganese nodules, colour mottles, strial, isotic and speckled plasmic fabrics, iron and clay grain coatings, burrows, bioturbation and pedorelicts. Calcite and iron oxide cements occur as late diagenetic features.

Microfacies 1 consists of quartz and feldspar-rich sandstone with occasional shale clasts and iron nodule pedorelicts. Microfacies 2 is a microlaminated sandstone which contains iron-manganese coated root traces and compound clay coatings along void channels. Microfacies 3 is a black, massive mudstone containing abundant plant fragments. Microfacies 4 is a gray mudstone containing micro-ripple cross-lamination. Microfacies 5 is massive red, green or gray mudstone. This microfacies occasionally contains transported plant fragments. Microfacies 6 is a microlaminated mudstone which commonly contains root traces, papules, iron oxide coatings and mottles, and shale clast and iron nodule pedorelicts. Microfacies 7 occurs in red and green mudstone and is intensively bioturbated. This microfacies also commonly contains colour mottles, iron nodules, iron void coatings, root traces and pedorelicts. Microfacies 8 occurs in red, green and gray mudstone, and is characterized by subangular blocky peds, many iron-manganese root traces, common iron mottles, occasional iron nodules and papules, weakly to strongly developed clay and iron coatings along void channels, and occasional burrows.

Microfacies sequences provide information on paleosol dynamics and floodplain development. Paleosols in alluvial landscapes have developed in response to the rates and types of sediment deposition as well as to environmental factors. Therefore, paleosols which developed in areas where sediment deposition was very frequent and large have been interrupted and the microfacies sequences show strong evidence of sedimentary stratification (Microfacies 2 and 6). Paleosols further from the channel reflect the duration of pedogenesis and have more highly differentiated profiles exhibiting evidence of clay illuviation and mineral weathering (Microfacies 8). Biotically dominated and cumulic soil profiles occur in intermediate locations (Microfacies 7).

The general similarity of profile trends and landscape associations of numerous sequences indicates an important universality of pedological processes in these alluvial landscapes. The paleosol stages are subdivisions within a continuous spectrum dominated by depositional and biotic features in incipient stages and by clay illuviation and redox processes in more mature phases. The microfacies indicate incipient to moderately advanced soil development on floodplains of generally low relief. The pedogenic processes are consistent with soil development under sub-humid to semi-arid, seasonal climatic conditions.
GRAIN SHAPE ANALYSIS OF COLD COASTAL SEDIMENTS, CANADA

M. W. Mackay, I.P. Martini

Grain shape of fine sand quartz grains carries information about the provenance and dispersal of clastic sediments (Ehrlich and Weinberg, 1970). Factors such as type of quartz, amount of abrasion, hence type and length of transport the particles have undergone contribute to the shape characteristics of the grains. In our research we wished to test whether cold climate conditions of cold temperate, subarctic and arctic environments contribute sensibly to the shape features, either by imposing different sedimentary regimes (for instance reducing the length of time sediment can move under ice free conditions) or by modifying the shape through freezing and thawing processes.

Two-dimensional grain shape can be quantitatively described by use of a Fourier series in closed form (Ehrlich and Weinberg 1970). Each point on the periphery of the grain may be expressed in polar coordinates about the grain centre of gravity. From the digitized outline of the grain, 96 radial distances are measured around the grain at equal intervals (θ) and are expressed using the following Fourier series,

\[ R(θ) = R_0 + \sum_{n=2}^{24} R_n (\cos nθ - \phi_n) \]

Each of the terms in the closed-form Fourier series represents a shape component, or harmonic. The series of harmonics can describe grain shape as precisely as required. We have chosen to use the first 24 harmonics. \( R_0 \) is equivalent to the average radius of the grain, \( n \) is the harmonic order (2 to 24 harmonics were measured per grain), \( R_n \) is the harmonic amplitude and \( \phi_n \) is the phase angle for the \( n \)th harmonic. The amplitude for each harmonic, \( R_n \), is a measure of the contribution from the \( n \)th harmonic to the shape of the grain. For example, grain elongation is measured by the contribution of the second harmonic, \( R_2 \), to the overall shape of the grain; triangularity is measured by the contribution of the third harmonic, \( R_3 \). The amplitudes of the higher harmonics measure elements of roundness.

The Fourier amplitudes of a given harmonic from measured grains of each sample are used to plot a "shape frequency distribution" unique to each sample. This distribution displays the frequency of occurrence of Fourier amplitudes at a given harmonic in selected classes (15) of amplitude values. The uniqueness of the shape frequency distribution reflects the provenance and/or dispersal histories of the sand samples (Ehrlich et al, 1980). The selection of the harmonic that carries the most shape information is achieved by evaluating the minimum entropy, or inter-sample variability, within the set of samples (Full et al 1984).

A total of 69 coastal samples were taken from Wasaga Beach (Cold Temperate), Hudson-James Bay (Sub-Arctic) and Foxe Basin (Arctic). Six hundred quartz grains from each sample were digitized using a Matrox board video-digitizer. Entropy analysis indicated the

![Shape Frequency Distribution Wasaga Beach](image1)

**Figure 1:** Wasaga Beach Sample Histogram

![Shape Frequency Distribution Foxe Basin](image2)

**Figure 2:** Foxe Basin Sample Histogram
12th harmonic to contain the most shape information. Q-mode factor analysis was applied to the "shape frequency distributions" of the 12th harmonic. A strong difference between sands of Foxe Basin from those of Wasaga Beach and Hudson-James Bay is shown by the "shape frequency distributions" of the samples derived through the Q-mode analysis (Figure 1 and 2). All other samples can be represented as proportions or mixtures of these extreme samples. A clear separation was not found between samples from different coastal environments in Wasaga Beach and Hudson-James Bay.

Preliminary considerations suggest that the Foxe Basin sands contain a mixture of well rounded, frosted grains and angular grains showing no or very few signs of abrasion. This may be related respectively to glacial and glacio-fluvial sands carried in by Pleistocene glaciers, and sands derived from igneous and metamorphic coastal outcrops. In Hudson-James Bay and Wasaga Beach grains derived directly (first cycle) from igneous and metamorphic grains are fewer.

THE FOUR COMPONENT SYSTEM CaO-P₂O₅-CO₂-H₂O AND THE BREAKDOWN OF APATITE

W. Chesworth and P. van Straaten

This is the simplest system useful in the study of the weathering of apatite. In this case hydroxyapatite serves as a model apatite. Figure 1a shows the position of Figure 1b in the four component system. The plane in $P_{CO_2} = 10^{1.5}$ kPa is close enough to the CO₂-free base of the tetrahedron that the substitution of calcite for portlandite in the compatibility figure is equivalent to a system in equilibrium with atmospheric CO₂ (Figure 1b) and thus virtually identical to that for the system CaO-P₂O₅-H₂O (see last year's annual report). Figure 2 is a schematic representation of the solubility isotherm exaggerated to separate invariant points A and B from each other.

At the earth's surface, apatite would weather ideally along the pH = 5.7 contour, up to a maximum represented by point x of Figure 2. It would then be stable indefinitely. However, in nature, soil processes (leaching, production of organic acids, breakdown of sulphides and so on) ensure that pH will not remain buffered at 5.7 but will change to lower values in humid climates, in materials free from carbonates. Taking the pH range of oxisols and ultisols to be 4.5 to 3.5, it would be possible for apatite to break down completely and for monsite to be stabilised. If apatite did not break down completely, it would also be possible for the assemblage apatite and monsite to buffer the solution at point B. Point C would not normally be reached in most weathering systems, though it would be possible to reach it in acid-sulphate types of weathering.

Figure 2 also has a bearing on ways of treating apatite as a source of plant-available P. Apatite can be made to yield its phosphate by:

a) maintaining the solution composition within the solution field and away from the A-B saturation curve. Providing a sink for Ca and/or P species (organic chelating agents, zeolites, acid producing fungi, etc.) could accomplish this;

b) acidifying the system to values below pH 4.5 so that apatite is completely destabilised. This is the basis of the acidulation and partial acidulation treatments of apatite, and of the use of MCP coatings, and of coupled reactions involving sulphides.

The next stage in this research will be to add the component Al₂O₃ so that the fixation of phosphate in acid systems may be modelled.

Figure 1. (a) 4 component tetrahedron showing plane where $P_{CO_2}$ is $10^{1.5}$ pka. (b) 25°C, 100 kPa total pressure compatibility diagram on this plane.
MODELLING METAL RETENTION BY SOILS

L.J. Evans and K.A. Bolton

The application of agricultural chemicals, landfill leachates, industrial wastes, sewage sludge, etc., onto land can cause potential contamination of ground water supplies by toxic metals. Soils are particularly important for the containment of these metals in that they contain both surface-active mineral and humic constituents. The formulation of various mechanistic models to quantify the retention of metals by mineral and organic soil constituents has been a focus of much research.

Possible mechanisms for metal retention in soils include:

- Specific adsorption as inner-sphere complexes on the surfaces of hydrous ferric oxides
- Specific adsorption as inner-sphere complexes on the edges of phyllosilicate clays
- Non-specific adsorption as outer-sphere complexes at the surfaces of phyllosilicate clays
- Formation of inner-sphere complexes with functional groups on soil organic matter.

A computer program written in QUICKBasic is currently being evaluated for cadmium retention on Ontario soils. The essential features of the model are outlined below and in Fig. 1.

The proton dissociation reactions at the surfaces or edges of minerals can be represented by the two surface acidity reactions:

\[ \equiv S\cdot OH^+ \rightleftharpoons \equiv S\cdot OH^- + H^+ \]

where \( \equiv S \) represents a surface site.

The reactions of divalent cations at these variable charged surfaces can be described by:

\[ \equiv S\cdot OH^- + Me^{2+} \rightleftharpoons \equiv S\cdot O\cdot Me^+ + H^+ \]

The equilibrium constants for the various reactions at the surfaces of hydrous ferric oxides and the edges of phyllosilicate clays are given by:

\[ K_{a1}^{\text{int}} = \frac{[\equiv S\cdot OH^-][H^+]}{[\equiv S\cdot O\cdot H^+] \exp(-\psi/F/RT)} \]

\[ K_{a2}^{\text{int}} = \frac{[\equiv S\cdot O^-][H^+]}{[\equiv S\cdot OH^-] \exp(-\psi/F/RT)} \]

\[ K_{Me}^{\text{int}} = \frac{[\equiv S\cdot O\cdot Me^+][H^+]}{[\equiv S\cdot OH^-][Me^{2+}] \exp(\psi/F/RT)} \]

where \( K_{a1}^{\text{int}}, K_{a2}^{\text{int}} \) and \( K_{Me}^{\text{int}} \) are the intrinsic conditional equilibrium constants, and \( \psi \) and \( \psi_n \) are the electrical potentials at the charged surface and at the plane of adsorption of the inner-sphere complexes.

The total number of surface sites is given by:

\[ N_s = [\equiv S\cdot OH^-] + [\equiv S\cdot OH^-] + [\equiv S\cdot O^-] + [\equiv S\cdot O\cdot Me^+] \]

The charge balance for the surface functional groups is:

\[ \sigma_s = [\equiv S\cdot OH^-] + [\equiv S\cdot O\cdot Me^+] + [\equiv S\cdot O^-] \]

The content of \( \equiv S\cdot O\cdot Me^+ \) sites can be calculated using the constant capacitance model in which it is assumed that the relationship between charge density, \( \sigma_s \), and electrical potential, \( \psi \), is given by:

\[ \sigma_s = \psi \kappa, \text{ where } \kappa \text{ is the capacitance,} \]
For metal complexation with soil organic matter, the humic material can be considered to act as simple diprotic acid, H₂L, and thus
\[ H₂L + Me^{2+} \rightleftharpoons MeL^+ + 2H^+ ; K_{MeL}. \]
The mass balance for organic species is given by:
\[ L_T = H₂L + HL^- + L^2^- + MeL^2. \]
In the presence of the background electrolyte LiClO₄, cation exchange reactions that involve the formation of metallic outer-sphere complexes with the surfaces of phyllosilicate clays can be described by:
\[ 2LiX + Me^{2+} \rightleftharpoons MeX₂ + 2Li^+ ; K_x \]
The Vanelsow selectivity coefficient, \( K_x \), for this reaction is:
\[ K_x = \frac{[MeX₂][Li^+]²}{[Me^{3+}][LiX]} \]
\[ = \frac{[MeX₂]}{[Me^{3+}][LiX]} \]

The cation exchange capacity, \( X_T \), for hydrolysable metals, the total content of metal in solution includes the hydroxo-species - \( MeOH^{+}, Me(OH)_2^{+}, Me(OH)_3^- \) and \( Me(OH)_2 \). The total mass balance, \( Me_T \), for metal containing species is therefore given by:
\[ Me_T = Me^{2+} + MeOH^{+} + Me(OH)_2^{+} + Me(OH)_3^- + Me(OH)_2 \]
\[ + S-O-Me^{+} + S-Cl-Me^{+} + MeL^+ + MeL^2 + MeX_2 \]
and the content of retained metal, \( Me_{net} \), given by:
\[ Me_{net} = S-O-Me^{+} + S-O-Me^{+} + MeL^+ + MeL^2 + MeX_2 \]

**EFFECTS OF FILTRATION AND IONIC STRENGTH ON BORON RETENTION BY SOILS**

*J. Hou and L.J. Evans*

There is increasing evidence that B complexation with organic ligands may be an important mechanism in the retention of B by soils. Conventionally, Millipore membrane filtration is used to separate solution and solid phases in batch adsorption experiments. However, the role of dissolved organic substances is difficult to assess because most of the dissolved organic carbon (DOC) passes through the membrane filter. This problem is of increasing importance for soils with high organic carbon contents. However, ultrafiltration techniques which utilize membranes with specific molecular weight cut-offs are a potentially useful alternative for separating colloidal and soluble organic substances from equilibrated solutions. The objective of this study was to evaluate B adsorption by two soils with differing organic matter contents using both separation techniques.

The studied soils were sampled from the Ap horizons of two Orthic Humic Gleysols - the Welland Series with 2.4% organic C and 44% clay; and the Cane series with 7.8% organic C and 54% clay. Boron adsorption experiments were conducted in batch systems with pH's adjusted from 3 to 10.5 and ionic strengths from 0.01 to 1.0M in LiCl. The initial B concentration was 1.028 mM. The amount of B adsorbed was calculated as the difference between the initial B concentration and the equilibrium concentration of B in the filtrates from either ultrafiltration using a 500 MW cutoff or filtration through a 0.45 μM Millipore filter.

Retention of B by the Cane soil was greater than that in the Welland soil throughout the whole experimental pH range of 3.5 to 10.5 (Fig.1 and Fig. 2), suggesting a significant role of soil organic matter content on B adsorption. The shapes of the adsorption envelopes for both ultrafiltration and Millipore filtration were essentially similar for the Welland soil with adsorption reaching a maximum at pH's between 8.5 and 9. This soil contained the lower amount of organic carbon. However, there was a significant difference in the shapes of the envelopes for the Cane soil after removing DOC from the filtrate by ultrafiltration. The adsorption envelope obtained using ultrafiltration did not show decreased adsorption after pH 9 but remained relatively constant up to a pH of 10.5.

For the Cane soil, B adsorption was found to increase in response to increasing ionic strength using Millipore filtration. Sorption of B on the Welland soil was also greatly increased by increasing the concentration of LiCl. However, the adsorption peak was shifted to a relative-
A CHEMICAL FRACTIONATION SCHEME FOR BORON IN SOILS

J. Hou, L.J. Evans and G.A. Spiers

Fractionation of trace elements in both solid and solution phases is of great interest in soil and environmental chemistry. The mobility of B in soils and the availability of B to plants is related to its association with various soil constituents, such as the type and content of clay minerals; Al, Fe oxides and (oxy) hydroxides; carbonate content; organic matter content and soil pH rather than to its total concentration.

Currently used fractionation schemes for trace elements in soil and sediments were reviewed and their suitability for the fractionation of B assessed. The following scheme was considered the most appropriate for testing:-

- Water-soluble-
  - extracted with 0.01 M CaCl₂
- Non-specifically adsorbed-
  - extracted with 0.05 M mannitol in 0.01 M CaCl₂
  - extract with 0.05 M NaHCO₃
  - extract with 0.05 M KH₂PO₄
  - extract with 0.02 M NH₄-oxalate
- Specifically adsorbed-
  - extract with HNO₃-H₂O₂
dissolved with HNO₃-HF-HCl

To evaluate the methodology, three B-sorbed and B-coprecipitated phases were prepared. These synthetic soils contained 5% calcite, 1-5% goethite, 30-50% clay mica, 5-15% humic acid and 60% silica powder (Table 1). The soils were amended with three levels of B in the form of boric acid. Each soil was extracted with the above reagents both sequentially and separately.
Table 1. Compositions of synthetic soils

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<th>Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
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<tr>
<td>Calcite - CaCO₃</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Goethite - FeOOH</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Clay mica</td>
<td>25</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>Humic acid</td>
<td>19</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Silica sand - SiO₂</td>
<td>50</td>
<td>50</td>
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Recoveries of amended B from sequential extractions ranged from 84.51 to 104.09 % with an average of 97.34 % and a standard deviation of 5.59 when 0.05 M KH₂PO₄ was used to extract specifically adsorbed B, and ranged from 76.9 to 99.0 % with an average of 88.98 % and a standard deviation of 7.49 when NaHCO₃ is employed. Correlation coefficients between added B and extracted B were highly significant for the following extractants: -0.01 M CaCl₂, \( r = 0.87^* \); 0.05 M mannitol in 0.01 M CaCl₂, \( r = 0.90^* \); 0.05 M KH₂PO₄, \( r = 0.97^* \); and 0.05 M NaHCO₃, \( r = 0.96^* \). The results also suggested that water-soluble B is better estimated by 0.05 M mannitol in 0.01 M CaCl₂ than by 0.01 M CaCl₂ and that KH₂PO₄ is a better extractant than NaHCO₃ for predicting specifically adsorbed B. Added B was also significantly correlated with the content of goethite in the synthetic soils, \( r = 0.70^* \), while structural B was significantly correlated with the content of clay mica, \( r = 0.91^* \).

SURFACE COMPLEXATION MODELLING OF MOLYBDENUM RETENTION BY TROPICAL SOILS

L.J. Evans and H.I. Oluku.

Deficiencies of a number of trace elements required for crop production have been reported for many tropical soils. Intensive weathering associated with higher temperatures and elevated rainfall can reduce the content of trace elements in soils; and secondly tropical soils often contain high amounts of secondary minerals, such as hematite and gibbsite, which have been implicated in the retention of trace elements by soils. Molybdenum deficiency typically occurs on leached, highly weathered, acidic soils, especially those developed from older parent materials.

Three Kenyan soils were chosen for investigation. The choice of the three soils was based mainly on variations in their pH values, their organic matter contents and their differing amounts of crystalline iron, \( \text{Fe}^{3+} \), as calculated by DCB-and oxalate-extraction.

For each soil, a range of pH values from 3.5 to 7.5 was obtained by addition of appropriate amounts of acid or base. After six days of equilibration, a Na₂MoO₄/LiClO₄ solution was then added. The tubes were shaken overnight, centrifuged and filtered through 0.22 \( \mu \text{m} \) Millipore filters. The amount of Mo remaining in the filtered solutions was measured by ICP-AES using a Leco Plasmarray. The amount of Mo adsorbed by the soils was calculated as the difference between the amount initially added and the amount remaining in solution.

The most appropriate surface complexation model to describe molybdate adsorption onto variable charge surfaces is the constant capacitance model. This is because the model assumes specific adsorption of anions onto the mineral surface and this adsorption mechanism is consistent with current theories of anion adsorption. In the development of the model it was assumed that the surfaces responsible for Mo retention by the soils occur on the mineral hematite.

To estimate the amount of hematite in the soils samples it was assumed that the calculated values of \( \text{Fe}^{3+} \) represented the content of this mineral. The formulation of the model and the adjustable parameters used are shown in Table 1. The actual and predicted adsorption envelopes are shown in Fig 1. From these figures it can be seen that the model underestimates the amount of adsorption at low pH's but approaches the experimental data at pH's
in excess of the maximum amount adsorption. The model is currently being refined by the inclusion of kaolinite adsorption sites into the model.

Table 1. Parameters used in constant capacitance model for molybdate retention

Dissociation and complexation reactions at the hematite surface:

$$\begin{align*}
\text{Fe-OH}_2^+ & \rightleftharpoons \text{Fe-OH}^- + \text{H}^+ & pK_{f1}^{\text{Fe}} &= 7.2 \\
\text{Fe-OH}^- & \rightleftharpoons \text{Fe-O}^- + \text{H}^+ & pK_{f2}^{\text{Fe}} &= 11.1 \\
\text{Fe-OH}^- + \text{MoO}_4^{2-} + \text{H}^+ & \rightleftharpoons \text{Fe-MoO}_4^{-} + \text{H}_2\text{O} & pK_{K_{Mo}}^{\text{Fe}} &= -9.2 
\end{align*}$$

Dissociation of molybdic acid in solution:

$$\begin{align*}
\text{H}_2\text{MoO}_4 & \rightleftharpoons \text{HMoO}_4^- + \text{H}^+ & pK_{a1} &= 4.52 \\
\text{HMoO}_4^- & \rightleftharpoons \text{MoO}_4^{2-} + \text{H}^+ & pK_{a2} &= 4.65
\end{align*}$$

The mass balance for the reactive sites, $N_4$:

$$N_4 = [\text{Fe-OH}_2^+] + [\text{Fe-OH}^-] + [\text{Fe-O}^-] + [\text{Fe-MoO}_4^-] \quad N_4 = 10^{3} \text{ M}$$

The mass balance for all the Mo-containing species, $[\text{Mo}]_	ext{r}$:

$$[\text{Mo}]_	ext{r} = [\text{H}_2\text{MoO}_4] + [\text{HMoO}_4^-] + [\text{MoO}_4^{2-}] + [\text{Fe-MoO}_4^-] \quad [\text{Mo}]_	ext{r} = 2 \times 10^{-4} \text{ M}$$

The surface charge density, $\sigma_s$, at the hematite surface:

$$\sigma_s = \left( [\text{Fe-OH}_2^+] - [\text{Fe-O}^-] - [\text{Fe-MoO}_4^-] \right) F / S_s S_p$$

where $S_s$ is the specific surface and $S_p$ is the suspension density

$$S_s = 80 \text{ m}^2 \text{ kg}^{-1} \quad S_p = 16.7 \text{ g L}^{-1}$$

Surface charge density, $\sigma_s$, - surface potential, $\psi_s$, relationship:

$$\sigma_s = \kappa \psi_s \quad \text{where } \kappa \text{ is the capacitance} \quad \kappa = 0.48 \text{ F m}^{-2}$$

Figure 1.
INFLUENCE OF SOIL PROPERTIES ON THE CHANGES IN AGGREGATE STABILITY SUBSEQUENT TO THE INTRODUCTION OF FORAGES

V. Rasiah and B. D. Kay

Structural stability of soil has an impact on a wide range of processes that influence crop growth, erosion, runoff, and the transport of contaminants from farm land to streams and surface water bodies. Limited information is available on the methodologies used to characterize the changes in structural stability with time subsequent to changes in management practices. A semiempirical model has been developed to predict the net gain in WAS, i.e., \( \text{WAS}_{\text{net}} \) using the WAS vs water content, \( \Theta \), relation:

\[
\text{WAS}_{\text{net}} = (\Delta a - \Delta b \Theta)(1-e^{-k \Theta}) + b_\varepsilon (\Theta - \Theta_0)
\]  

[1]

where \( \text{WAS}_{\text{net}} = \text{WAS}_c - \text{WAS}_f \) and the subscripts \( c \) and \( f \) refers to corn and forage treatments, respectively.

Equation [1] allowed the estimation of the duration of delay, \( t_d \), before any observable changes in WAS occurred subsequent to the introduction of forages, the rate constant \( k \) which defined the rate at which WAS increased from an initial to a maximum value, the initial sensitivity, \( b_\varepsilon \), of WAS to \( \Theta \), and the parameters \( \Delta a \) and \( \Delta b \) which determined the maximum change in WAS(\( \Theta \)). The time required for a forage to improve the WAS of a soil to a point midway between the initial and maximum value is a meaningful variable for advisory purposes and it is defined as half-life \( t_{1/2} \):

\[
t_{1/2} = t_d - \ln(0.5)/k
\]  

[2]

Soil samples for WAS measurement were collected at monthly intervals during the 1989, 1990, and 1991 growing seasons from seven different soils under conventionally tilled corn and forage treatments established in 1989. Prior to 1989, the experimental sites were under

Figure 1.

Figure 2.
conventionally cultivated continuous corn for at least 10 yr.

The half-life, $t_{1/2}$, for aggregate stabilization ranged from 4.52 yr for a clay loam, to 7.75 yr for a sandy loam. The WAS$_{net}$ increased with increasing $\Delta a$ and $k$ and decreasing $\Delta b$, $b_o$, and $t_i$.

The pedotransfer functions which related each of the parameters; $\Delta a$, $\Delta b$, $b_o$, $k$, and $t_i$ with selected soil properties were significant exclusive of that established for $\Delta a$. The established functions indicated that values of $k$, $t_i$, $\Delta b$, and $b_o$ increased with increasing in clay content (Fig. 1). At a given clay content the values of $t_i$, $\Delta b$, and $b_o$ decreased with increasing OM content per unit weight of clay and pH.

The WAS$_{net}$ of soils with different clay contents decreased in the order 34% clay, 20% clay, 6% clay (Fig. 2). The analysis indicates that higher the level of OM content at the time of introduction of the forages, the larger was the increase in WAS$_{net}$. The response to higher levels of OM increased with time and appeared to be independent of clay content. The response to an increase in pH, from 5.77 to 7.3, on WAS$_{net}$ showed trends similar to those observed for the change in OM content. However, the response to changes in pH appeared to be dependent on clay content, i.e., increased with increasing clay content. The analyses indicate the regeneration of soil structural stability depends on texture, particularly the clay content, and the initial concentration of stabilizing materials. Higher the initial concentration of the stabilizing materials in soil, the sooner was the stabilization commenced, i.e. smaller the values of $t_i$.

**CLAY STABILIZATION SUBSEQUENT TO THE INTRODUCTION OF FORAGES: INFLUENCE OF SELECTED SOIL PROPERTIES**

V. Rasiah, and B. D. Key

Introduction of forages onto structurally degraded soils is known to have positive influence on stability. Structural stability can be characterized at different size scales. Dispersible clay, DC, has been used as an index of structural instability at the scale of clay size particles. The rate of regeneration of stability may depend on soil properties.

A semi-empirical model was developed to predict the net amount of clay stabilized, SC$_{net}$, subsequent to the introduction of forages:

$$\text{SC}_{\text{net}} = (\Delta v - \Delta q \Theta) (1 - e^{-k}) + \Delta q (\Theta - \Theta_0) \quad [1]$$

where SC$_{net}$ is defined as follows:

$$\text{SC}_{\text{net}} = [(\text{TC} - \text{DC}) - (\text{TC-DC}_0)] \quad [2]$$

In Eq. [1], $k$ is the rate constant, $\Delta q$ is the projected maximum increase in the sensitivity of stabilized clay, SC, to water content, $\Theta$, at sampling, $\Delta v$ is the projected maximum increase in SC at low $\Theta$, $q_e$ is the sensitivity of SC to $\Theta$ at sampling in the control, the corn, and TC is the total clay content. The subscripts c and f refer to corn and forage treatments, respectively. The model was assessed using data collected from seven soils at monthly intervals in 1981, 1990, and 1991 from the corn and the forage phase of corn-forage rotation experiments initiated by different investigators in 1989.

The ability of the forages to stabilize clay can be characterized by the maximum potential increase in stabilized clay, $\Delta SC(\Theta_0)$, at the average water content, $\Theta_0$, of the forage treatment and is given by

$$\Delta SC(\Theta_0) = (\Delta v - \Delta q \Theta_0) \quad [3]$$

The time required for the forages to increase SC$_{net}$ of a soil to a point midway between the initial to the maximum value can be defined the half life, $t_{1/2}$:

$$t_{1/2} (\text{SC}_{\text{net}}) = t_i - \ln(0.5)/k \quad [4]$$

The amount of dispersible clay that can potentially be stabilized by forages in relation to that present in the corn treatment, i.e. $\Delta SC(\Theta)/\text{DC}_C(\Theta)$, was also computed. Values of $k$, $\Delta q$, and $\Delta v$ increased with increasing clay and organic matter, OM, contents and pH of the soil (Fig. 1). The maximum potential amount of clay that can be stabilized, $\Delta SC(\Theta_0)$, by forages and the amount of clay stabilized by forages in relation to that dispersed in the control corn treatment, i.e. $\Delta SC(\Theta)/\text{DC}_C(\Theta)$, increased with increasing clay content. The half-life, $t_{1/2}$, for clay stabilization decreased with increasing clay and OM contents and soil pH. At a given clay content, 20%, and pH, 5.77, an increase in OM
content, from 2.2 to 3.8%, resulted in 80% increase in SC_{net}, 84% increase in \Delta SC(\Theta), and 48% increase in \Delta SC(\Theta)/DC_{(\Theta)}. For the same increase in OM content the \tau_{50} decreased by 1.5 yr. Trends similar to those observed for the increase in OM content were observed for an increase in pH from 5.77 to 7.33.

Clay stabilization subsequent to the introduction of forages increased with time and this increase was greater with increasing clay and OM contents and pH. An increase in OM content from 2.2 to 3.8\%, at the time of introduction of forages, in a soil with 34\% clay and a pH of 5.77, resulted in the values of SC_{net} to increase from 1.2 to 2.3\% in 3 yr. The corresponding increase in the soil with 20\% clay content was from 0.4 to 0.90\% in 3 yr. Trends similar to that observed for an increase in OM content were observed for an increase in pH from 5.77 to 7.3, but the magnitude of the increase was much smaller (Fig.2).
QUANTIFYING DRY AGGREGATE SIZE DISTRIBUTIONS IN TILLED SOIL

E. Perfect, B.D. Kay, J.A. Ferguson, A.P. da Silva, and K. Denholm

The dry aggregate size distribution (DASD) of tilled soil has been shown to influence the germination and establishment of agricultural crops. Parameters are needed to characterize the DASD for inclusion in crop growth models and for the evaluation of tillage tool performance.

We compared the log-normal, fractal and Rosin-Rammler functions as quantitative descriptors of the DASD after tillage. These functions were fitted to data from flat and rotary sieve analyses. Cumulative energy input due to tillage and sieving was kept constant. Comparisons were made on the basis of soil fragmentation theory, number of fractions fitted, goodness of fit and parameter sensitivity to soil properties.

All three functions resulted in a more accurate description of seed bed conditions than the use of individual size classes. However, the Rosin-Rammler function was the most robust, and is recommended for use in future studies. This function assumes the probability of aggregate failure decreases with decreasing size, which is consistent with soil fragmentation theory. Another advantage is its ability to fit over the entire range of size classes available. The R² was > 0.975 for a wide range of DASD's. The Rosin-Rammler scale parameter, α, gave the best correlation with soil properties. The α parameter is the aggregate size corresponding to the 36.78th percentile of the cumulative probability distribution. Thus, it is qualitatively similar to the mean size (i.e. 50th percentile) of a normal distribution. A small α denotes a distribution dominated by small aggregates and vice versa.

The α increased with increasing clay content at a site with different textures and the same cropping history. At a site with a uniform texture (silt loam) and different cropping histories, the α decreased with increasing time under forages (Fig. 1). Water content at time of cultivation was a significant covariate. Thus, the values of α in Fig. 1 are the least squares adjusted means.

![Fig. 1. Comparison of α's (least squares adjusted means) for seed beds prepared following: 4-yr conventional-till corn (C4), 4-yr conventional-till corn underseeded to red clover (CR4), 2-yr alfalfa followed by 2-yr conventional-till corn (A2C2), 2-yr bromegrass followed by 2-yr conventional-till corn (B2C2), 4-yr alfalfa (A4), and 4-yr bromegrass (B4).](image_url)
MEASURING SOIL FRAGMENTATION PARAMETERS

E. Perfect and B.D. Kay

Soil fragmentation parameters are needed in tillage and erosion studies. Ease of fragmentation is often reported in terms of wet-aggregate stability. However, the energy input associated with this measurement is difficult to quantify. To overcome this limitation we are investigating the use of tensile strength and rupture energy as alternative parameters to describe soil fragmentation. The tensile strength, \( \sigma \), is defined as:

\[
\sigma = \frac{kF}{x^2} \text{ [Pa]}
\]

where \( k \) is a proportionality constant that represents the ratio of tensile strength to compressive strength (\( k = 1.86 \) for air dry aggregates), \( F \) is the force at rupture \( \{N\} \), and \( x \) is an effective linear dimension, calculated as follows:

\[
x = \left( \frac{M}{M'} \right)^{1/2} (x_i + x_{i+1})/2 \text{ [m]}
\]

where \( M \) is the individual aggregate mass \( \{g\} \), \( M' \) is the mean mass of all aggregates \( \{g\} \) passing a sieve with openings of size \( x_{i+1} \text{ [m]} \) and collected on a sieve with openings of size \( x_i \text{ [m]} \). The rupture energy \( (E) \) is defined as:

\[
E = \int_0^1 F \, dl/M \, (l/g)
\]

where \( l \) is the displacement at rupture \( \{m\} \).

The above parameters are being measured in our laboratory using an ELE Digital Tritest 50 in compression mode. Aggregates are crushed between a pair of parallel flat plates. The unit is instrumented with load cells for measurements of \( F \) up to 334 N and a linear displacement transducer for measurements of \( l \) up to 5x10^{-2} m.

Instrumentation control and data acquisition are achieved using Sciometric System 200 hardware interfaced to a Compaq 286 computer through an 802 interface card. Tests are programmed using the Sciometric Benchmate software package. The unit is operated at a speed of 1.6-7x10^4 m/s. Tests terminate automatically when the aggregate ruptures. Each test, including aggregate weighing, positioning, crushing and removal, takes approximately 2 minutes to perform. Data can be stored on a floppy diskette and retrieved in spreadsheet format. The results of a typical aggregate rupture test are shown in Fig. 1.

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**Fig. 1.** Force-displacement curve for an air dry aggregate of length \( x = 14.29 \text{ mm} \) from the seed bed of a silt loam soil under conventional-till corn production. \( F \) is the force at rupture, \( l \) is the displacement at rupture, and the shaded area under the curve divided by the aggregate mass, \( M \), is the rupture energy \( (E) \).
SOLUTE TRANSPORT IN LAYERED COARSE-TEXTURED UNDISTURBED SOIL COLUMNS

A.L. Ward, R.G. Kachanoski, and D.E. Elrick

Layered, coarse-textured, rapidly-draining soils occupy a significant portion of arable land in S.W. Ontario. Many have a B_w horizon, characterized by a periodic tonguing, as well as a higher saturated hydraulic conductivity and capillary length compared to the Ap and Ck horizons. This suggests the presence of more large pores and the ability to transport water and solute at high rates. These tongues, many of which extend beyond 3 m, may well be localized zones of rapid solute transport. Thus, the study of solute transport must address movement through layers with distinctly transport properties and interfacial conditions. A recent approach to modelling transport in heterogeneous soils is the stochastic-convective approach. This approach requires information on the joint probability density functions (pdfs) of hydraulic and transport properties and their correlation in individual layers.

Laboratory transport experiments in layered soils offer the most convenient approach to obtaining this information and the subsequent deduction of the form of the travel time pdfs of the individual layers. In view of this, 50 undisturbed columns (1.5 m long, 0.15 m diameter) of a coarse-textured, layered soil were instrumented with TDR probes and tensiometers to measure hydraulic and transport properties. Transport experiments were repeated at three constant flux densities of water, J_w, with the objective of collecting a comprehensive data set of flow and transport conducted under controlled boundary conditions.

Here, we show examples of the type and extent of data collected as well as the information that can be

Figure 1 Spatial distribution of (a) horizon thickness and measurement points, (b) solute velocities.

Figure 2 Solute BTCs at 1.1 m for 3 constant fluxes during 1-D transport in an undisturbed column.
inferred from these measurements. Figure 1a shows distribution of horizon thickness in the soil profile from which the columns were obtained, along with the corresponding points of measurement in the instrumented columns. At each point, observed data includes thickness of the A and B horizon; the dependence of water content on pressure head, \( \theta(\psi) \); the dependence of hydraulic conductivity on pressure head, \( K(\psi) \). TDR measured solute breakthrough curves provided estimates of transport parameters, and the pdfs of solute travel-time, at three constant flux densities. Based on measurements of travel-time, velocities can be calculated for the different depth increments. Figure 1b shows a plot of solute velocity from the about 60 cm \((v_1)\), and from 60 cm to 100 cm \((v_2)\). Although analysis indicates a small positive correlation between \( v_1 \) and \( v_2 \) \((r=0.2)\), there is a strong correlation between \( v_2 \) and the thickness of the B horizon. Thus it should be possible to obtain the joint pdfs of hydraulic and transport properties, and horizon thickness for use in stochastic-convective models of transport.

Fitted transport parameters are integral values from the surface to the measurement depth. However, the frequency and consistency of the data should allow accurate deconvolution of successive curves for parameter estimation on individual depth increments. The data set also identifies other features of transport in coarse textured soils, such as bimodal BTCs (Fig. 2) at a depth of 1.1 m in one column. This feature was evident at all three values of \( J_{\psi} \).

An interesting observation is that as \( J_{\psi} \) decreased, the relative amount of solute associated with the second slower peak of the BTC increased. The bimodal BTC is not attributed to preferential flow along the casing of the core, because it was observed even at the lowest flux, \( J_{\psi} = 2.62 \) cm d\(^{-1}\) where the mean \( \theta \) was 0.11 m\(^2\) m\(^{-3}\). This data set will prove to be very useful in the validation of both stochastic and deterministic models of flow and transport.

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**TEMPERATURE DEPENDENCE OF TDR MEASURED WATER CONTENT AND BULK ELECTRICAL CONDUCTIVITY**

A.L. Ward, E.A. Pringle and R.G. Kachanoski

Departmental research conducted over the last five years has shown time-domain reflectometry (TDR) to be a quick, inexpensive and accurate method for obtaining simultaneous, nondestructive estimates of the spatial and temporal distribution of water content, \( \theta \), and bulk electrical conductivity, \( \sigma_r \), in soil. Measurements of \( \sigma_r \) may then be used to estimate flux and resident concentrations of inert solutes. Estimates of \( \theta \) are obtained by the universal, empirical \( \theta(\kappa) \) relationship. The apparent dielectric constant, \( \kappa_a \), is usually inferred from measurements of transit time. The \( \theta(\kappa) \) relationship assumes independence of soil type, bulk density, soil temperature \((T)\), and salinity. Estimates of \( \sigma_r \) are obtained simply from

\[
\sigma_r = \frac{1}{Z_r} \tag{1}
\]

where \( Z_r \) is impedance measured after all multiple reflections have ceased.

Experience has shown unexplainable yet periodic variations in TDR measured \( \theta \) and \( \sigma_r \), especially in long term field experiments. The objective of this research was to investigate the effects of temperature on TDR measured \( \theta \) and \( \sigma_r \).

Six 7 cm diameter, 15 cm long acrylic columns were packed to a bulk density of 1.6 Mg m\(^{-3}\) using C horizon material of Caledon sand. Five concentrations of KCl ranging from 0.05 M to 0.4 M were used to bring five columns to an equilibrium \( \theta \) of 20.0%. The sixth column served as a control and was treated with only distilled water. The columns were instrumented with 13 cm long paired-parallel TDR probes and placed into a water bath. The columns were brought to equilibrium temperatures ranging from 0 to 60 °C. Soil temperatures were recorded and at equilibrium, measurements of signal transit time and \( Z_r \) were obtained using TDR. Transit times were used to calculate \( \theta \) as a function of temperature using \( \theta(\kappa) \), while measurements of \( Z_r \) were used to calculate \( \sigma_r \) using Eq. [1].

Figure 1a shows a plot of \( \kappa \) as a function of \( T(°C) \) for different
resident solute concentrations, $C_R$. The control column ($C_R = 0$ M KCl) shows a relatively constant value of $\kappa$ as temperature increases. This is consistent with the assumptions on which $\theta (\kappa)$ is based. However, as the concentration increases, the slope of the curve gradually increases, eventually becoming nonlinear. This results in an overestimation of $\kappa$ relative to the control column. Predictions of $\theta$ can be expected to display a similar response. The failure of the control column to show response to temperature suggests that the observed trends may be related to the presence of solute.

Measurement of $\theta$ is based on the similarity between the real component of the complex dielectric constant, $\kappa$, and $\kappa$. A voltage pulse propagating in a conductive medium usually undergoes some signal loss due to attenuation of the wave while in a homogeneous non-conductive medium, this loss is minimal. However, in a highly conductive medium, signal attenuation, thus, the dielectric loss factor, can be quite significant and the assumption that $\kappa = \kappa$ is no longer valid. The empirical $\theta (\kappa)$ relationship may then prove to be inappropriate resulting in an overestimation of $\theta$. TDR measurement of $\theta$ also depends on an impedance difference between the probe and soil to ensure an in-phase reflection of the wave at the end of the probe. As the amount of solute concentration increases, the impedance difference becomes smaller until eventually the soil conducts the EM wave just as efficiently as the probes. The result is very little or no reflection, thus making the measurement of the break-point highly subjective. Usually, as concentration increases, the transit time shows an apparent increase for the same reason thus $\kappa$ and $\theta$ are over estimated.

Figure 1b shows a plot of $\sigma_T$ as a function of $T$ for six different concentrations of KCl. As in the case of $\kappa$ measurements, the control shows no significant response. However, as $C_R$ increases, the slope gradually increases. The apparent increase in $\sigma_T$ with $C_R$ and $T$ is believed to be caused by an interaction between ion mobility, viscosity, and temperature. It has been shown that the viscosity of a solution varies inversely with $\sigma_T$ and $T$. Thus, as $T$ increases, reduced viscosity and increased ionic potential energy results in an increase in ion mobility, which is manifested as an increase in $\sigma_T$. Thus, mathematical relationships between TDR measured $\sigma_T$ and $T$ can be derived from which the necessary correction factors can be calculated.

Based on these observations, it can be concluded that temperature can have significant effects on the TDR measurement of $\theta$ and $\sigma_T$. This may serve to explain the correlation between the time-of-day that TDR measurements were made and the variability in $\sigma_T$. Unless this variability is considered, and the necessary corrections made, erroneous predictions of these two very important properties may result in erroneous conclusions in flow and transport experiments.

Figure 1 Effect of temperature on TDR measurements (a) $K$, (b) $\sigma_T$. Mean $\theta = 0.20$, probe length = 13 cm.
AN IMPROVED TDR PROBE FOR THE MEASUREMENT OF SOIL WATER CONTENT AT HIGH SALINITY LEVELS


Time Domain Reflectometry (TDR) is now an established method for the nondestructive measurement of soil water content, \( \theta \), and electrical properties including bulk electrical conductivity \( \sigma_f \) from which transport properties can be inferred. To be of practical use, a TDR generated electromagnetic wave must enter the soil via a set of probes. The most common probe is the parallel, two-wire, probe constructed of stainless steel which is embedded in the soil whose properties are to be measured. The TDR may then be used to obtain simultaneous measures of \( \theta \) and \( \sigma_f \) in the same volume of soil.

Accurate estimation of \( \theta \) requires accurate measurement of the transit time, but this can only be achieved if the break points in the wave are easily identifiable. In a homogeneous, non-conductive medium, this point is very distinct (Fig. 1). However, in a conductive medium attenuation due to conduction losses, and similarities in the impedance of the soil and the probe reduce the accuracy with which this point can be determined (Fig 1). As the salinity level increases, the location of the breakpoint becomes more subjective and transit time can be severely overestimated leading to erroneous predictions of \( \theta \). This problem is further aggravated at high soil temperatures and can have serious consequences in solute transport studies. Solute velocity is inversely proportional to \( \theta \), thus overestimation of \( \theta \) can result in underestimation of solute velocity and incorrect solute transit times. The inability to accurately measure \( \theta \) at high solute concentrations is therefore a major limitation in the use of TDR. The major objective to this research was to develop a probe that would permit the simultaneous measurement of \( \theta \) and \( \sigma_f \) at high levels of salinity.

The theory behind the design of the new probe is based on the mathematical analysis of the air-gap problem for parallel wire transmission lines. The development of airgaps during probe insertion results in an underestimation of the apparent dielectric constant.

The problem of measuring \( \theta \) under conditions of high salinity and temperature is exactly the opposite - there is usually an overestimation of the apparent dielectric constant. Separation of the probe from direct contact with the soil using a material of a different permittivity may therefore be advantageous and forms the basis of the new probe. This theory also provides an analytically tractable boundary value problem. Based on this analysis, a new probe which consists of stainless steel rods coated with a nonconductive material of different permittivity was designed. After initial investigations using paint, epoxy resin, PVC heat-shrink tubing, silicone based insulators, and automotive ceramic, PVC heat-shrink proved to be the most convenient to use.

Initial evaluation of the new probe in soil columns under the same conditions as described in the previous paper. Figure 1 shows a sample TDR trace comparing the standard and new probes in soil containing a 0.4 M KCl solution at a water content of 22%. The coated probes clearly permits the identification of the break-point used for calculating \( \kappa_{c} \). Figure 2 shows a semilogarithmic plot of \( \kappa_{c} \) as a function of temperature for 5 concentrations of KCl using both probes. With the standard probe, an increase in concentration is accompanied by an increase in the slope of the curve with the response eventually becoming nonlinear. This results in an overestimation of \( \kappa_{c} \) relative to the control column. The coated probes are less responsive to temperature. Since \( \theta \) is dependent on \( \kappa_{c} \), predictions of \( \theta \) can be expected to display a similar response.

Figure 3 shows semilogarithmic plots of \( \sigma_f \) as a function of T for the different concentrations of KCl. With the standard probes, \( \sigma_f \) ranged over two orders of magnitude, while with the coated probe it fell between 3.4 x 10^3 and 3.6 x 10^3 mhos. The small range in \( \sigma_f \) for the coated probes shows their potential in reducing the error associated with estimating \( \kappa_{c} \). Although the low sensitivity of the coated probe corrects the problem incurred in estimating \( \theta \), it is a source of concern when measurements of \( \sigma_f \) for the estimation of transport properties are required. The ideal probe should therefore incorporate the benefits of the coated probe to permit measurement of \( \theta \), yet retain the sensitivity of the standard probe to changes in concentration and conductivity. Such a probe has been designed and is currently being evaluated.
Figure 1. TDR waves for standard and coated probes in a soil containing a 0.4 M KCl solution.

Figure 2. Temperature dependence of $K_\mu$ for various solute concentrations with the coated TDR probe.

Figure 3. Temperature dependence of $1/Z_p$ for various solute concentrations with coated TDR probe.
FIELD MEASUREMENT OF HYDRAULIC CONDUCTIVITY IN SLOWLY PERMEABLE MATERIALS USING EARLY-TIME INFILTRATION MEASUREMENTS IN UNSATURATED MEDIA

D.J. Fallow, D.E. Elrick, W. D. Reynolds, N. Baumgartner and G.W. Parkin

Most procedures to measure the hydraulic conductivity of slowly permeable materials such as compacted soil liners are based on analyses that assume saturated, one-dimensional flow under steady-state conditions. The overwhelming problem, however, is the very long times, of the order of weeks or months in liner materials, to reach experimentally-measurable steady flow. A new field procedure is proposed for slowly permeable materials that takes advantage of the early transient flow in initially unsaturated soil. Both constant head and falling head techniques are proposed and measurement times are of the order of one half to several hours. The falling head technique has the advantage of requiring only the difference between the field-saturated and initial water contents in addition to the measured position of the falling head above the soil surface as a function of time. An experiment on the experimental soil liner at Champaign, Illinois, gave saturated hydraulic conductivity values using the constant head technique that were in good agreement with previously measured values. A laboratory test demonstrated the advantages of the falling head technique.

The cumulative infiltration as a function of $t^{1/2}$ is shown in Figure 1 for a laboratory packed clay soil. The dashed line shows what the cumulative infiltration would have been for constant head conditions. The experimental data and the best-fit falling head equation compare quite favourably. The best fit values of $K_h$ and $\alpha^*$ are $1.44 \times 10^8$ ms$^{-1}$ and $1.76$ m$^4$ respectively, well within expected value for a laboratory packed sample. The procedure should work for $K_h$ values as low $10^{-9}$ to $10^{-11}$ ms$^{-1}$.

![Figure 1. The data points show cumulative infiltration, $I$, as a function of $t^{1/2}$ and the solid line is the non-linear least square fit of the falling head equation. The dotted line shows what $I$ would have been if the head had remained constant at its initial value.](image)

HYDRAULIC CONDUCTIVITY CHANGES WITH BARE AND SODDED SOILS

N. Baumgartner, W.G. Wilson, R.P. Voroney

Twenty-four 0.65m$^2$ micro-green lysimeters at the Cambridge Research Station were dug up after removing the old sod. Twelve lysimeters were repacked with alkaline sand. Twelve with acid sand. Six of each contain peatmoss and four zeolite soil amendments. The peat or zeolite occupy 20% by volume. There were four control plots of which two contain only alkaline sand, the others only acid sand.

After allowing the mixtures to settle for about one month, the field-saturated hydraulic conductivity ($K_h$) was measured using a small diameter Guelph Pressure Infiltrometer* on each plot.

The measurements were repeated one year after the sod was laid down to assess changes with time.

The $K_h$ was reduced from about 75cm per hour before to establishment of the sodded greens to 50cm per hour. However, this would not prevent adequate water movement through the rooting zone. The $K_h$ measurements will be continued.

*Soil moisture Equipment Corp.
COMPACTION OF AN EARTHY SAND IN WESTERN AUSTRALIA BY RUBBER TRACKED AND TYRED VEHICLES

B.G. Blunden (CSIRO, Canberra), R.A. McBride (Univ. of Guelph), H. Daniel (Univ. of Western Australia) and P.S. Blackwell (Western Australia Dep't of Agriculture)

A study was undertaken in 1992 to examine the compaction of an earthy sand in Western Australia by rubber tracked and tyred agricultural vehicles. Normal stresses exerted by two agricultural vehicles (a rubber tracked Caterpillar Challenger 65 and a Steiger "Tiger" 550 4WD tractor fitted with low pressure dual wheels) were measured with electronic earth pressure cells at four depths (15, 30, 40, 50 cm) in a wheat paddock. Cone penetration resistance and dry bulk density were also measured at these depths before and after traffic treatments. Uniaxial soil compression testing was limited to soil cores sampled at the 30 cm depth where the peak normal stresses were measured during vehicle passage. The Cat 65 exerted less normal stress on the soil than did the Steiger 550. The magnitude of the normal stress was also attenuated more with increasing depth for the Cat 65 than for the Steiger 550 (Figs. 1 and 2). The soil had a higher penetration resistance, however, after the passage of

Plate 1. The Steiger 550 in a loaded configuration approaching the instrumented plot area.

Figure 1. Normal stress waveforms at three depths beneath a Cat Challenger 65 (unloaded) on a sandy wheatbelt soil.

Figure 2. Normal stress waveforms at three depths beneath a Steiger 550 (unloaded) on a sandy wheatbelt soil.
the Cat 65 relative to the Steiger 550 (Fig. 3). This may indicate that significant shearing occurred beneath the Cat 65 tracks. Profiles of cone penetration resistance were more discriminating than dry bulk density and most of the parameters derived from compression testing in distinguishing soil physical changes among the trafficked and untrafficked treatments.

Figure 3. Profiles of cone penetration resistance for all traffic treatments. (▼ Cat 65 loaded, ▲ Cat 65 unloaded, • Steiger 550 loaded, ○ Steiger 550 unloaded, □ untrafficked condition) (± = standard error)

EVIDENCE FOR TRANSIENT STRENGTHENING AND NATURAL COMPACTION BY EFFECTIVE STRESS DEVELOPMENT IN A LOAMY SAND IN WESTERN AUSTRALIA

R.A. McBride (Univ. of Guelph), H. Daniel (Univ. of Western Australia) and P.S. Blackwell (Western Australia Dep't of Agriculture)

A second soil compaction study was carried out in 1992 on Western Australian loamy sands. The experiment was carried out at the Wongan Hills Research Station on a long-term plot installation where no wheel traffic was allowed for a period of about 10 years. The principal finding was that both the cone penetration resistance as measured in the field and the preconsolidation stress as measured in the laboratory by static, uniaxial compression of intact soil cores increased significantly (P < 0.05) with time. This effect was attributed to effective stress development during the extreme seasonal wetting and drying cycles in the WA wheatbelt. The compression lines for these same soils showed a marked increase in void ratio (i.e. decrease in dry bulk density) at a given load as the moisture content decreased, but also showed a significant decline in the compression index (i.e. slope of the virgin compression line in e-log o'co-ordinates) with drying to an air-dry condition. This finding was attributed to transient strengthening with cementing agents (e.g. goethite, kaolinite). Laboratory experiments are now underway to assess the importance of these mechanisms in coarse-textured Ontario soils. Intact soil cores will be subjected to controlled wetting and drying cycles while contained in a Rowe consolidation cell where soil strain and pore water pressure can be precisely monitored over time.

Plate 1. Dr. Daniel operating the modified Bush recording cone penetrometer at the Wongan Hills Research Station.
ANALYSES OF N\textsuperscript{15} IN SOIL AND PLANT SAMPLES

D.A. Tel and A. Schlosser

About a year ago our VG602E Mass Spectrometer was updated and modified. The Robo Prep was purchased, providing an on line "coupling of an automated Dumas combustion" sample preparation unit to our Mass Spectrometer. This allows measurements of not only total nitrogen or carbon in a sample but also their N\textsuperscript{15} or C\textsuperscript{13} levels in a wide range of biological and chemical samples.

Sample materials containing carbon and nitrogen are loaded into tin capsules and dropped into a furnace at 1000\degree C while in an atmosphere of oxygen. The tin ignites and burns exothermically, and the temperature rises to about 1800\degree C, oxidising the sample. Complete oxidation is ensured by passing the combustion products through a bed of chromium trioxide at 1000\degree C using a helium carrier gas. A 15 cm. layer of copper oxide followed by a layer of silver wool completes the oxidation and removes any sulphur. The products are then passed through a second furnace containing copper at 600\degree C where excess oxygen is absorbed and nitrogen oxides are reduced to elemental nitrogen. Water is removed in a trap containing anhydrous magnesium perchlorate and carbon dioxide in a trap containing "Carbosorb" (water only is removed if carbon dioxide is the gas of interest). The gas stream passes into a gas chromatograph where components of interest are separated and is then bled into a mass-spectrometer where the nitrogen isotopes are ionised then separated in a magnetic field. The isotope species are detected separately and from their ratios, the level of N\textsuperscript{15} calculated. Calibration of the system is made using known standards allowing both total nitrogen and N\textsuperscript{15} content to be obtained from each sample.

Several faculty members of LRS have research projects involving the use of the N\textsuperscript{15}. This generates about 20,000 samples a year. The number of samples makes us the laboratory with the highest sample throughput/mass spectrometer. To attain this goal, extra help was needed and a cost recovery set up was put in place.

Within the Land Resource Science analytical Services department, the Nitrogen Analysis program was created and Angela Schlosser was hired to assist me in this program. Angela has done a great job so far and we are looking forward to serving the members of this department, the University of Guelph and outside contract work. Both Angela and I would be pleased to be informed about your future plans in Nitrogen Research, suggestions on improvements in the program are welcome.

SOIL ELECTRICAL CONDUCTIVITY VERSUS NITRATE AND OTHER ANION CONCENTRATIONS

B.J. Farquharson and E.G. Beauchamp

The "Soil Doctor" is a nitrogen applicator designed to deliver varied rate of nitrogen. Rates of nitrogen application are determined by a probe or sensor measuring nitrate concentration in the soil. The principle involved is believed to be a measure of electrical conductivity that is related to the NO\textsubscript{3}\textsuperscript{-} concentration. The sensor is connected to a computer in a fertilizer applicator that varies the quantity of N fertilizer applied. Thus, in soils with low nitrate concentration a higher rate of nitrogen is applied and in soils with high nitrate concentration a reduced amount of nitrogen is applied.

The objective of the study was to determine the effects of concentrations of NO\textsubscript{3}\textsuperscript{-} and other anions (F\textsuperscript{-}, Cl\textsuperscript{-}, NO\textsubscript{2}\textsuperscript{-}, PO\textsubscript{4}\textsuperscript{3-}, SO\textsubscript{4}\textsuperscript{2-}, HCO\textsubscript{3}\textsuperscript{-} and CO\textsubscript{3}\textsuperscript{2-}) on the electrical conductivity of some Ontario field soils. Soil samples with low and high N inputs at beginning of growing season were collected in the fall from 22 field sites in southwestern Ontario. The samples were air dried and sieved (2 mm) prior to analysis. Electrical conductivity (mS*cm\textsuperscript{-1}) was determined using a H\textsubscript{2}O:soil ratio of 2:1 by volume. Concentrations were determined by HPLC for F\textsuperscript{-}, Cl\textsuperscript{-}, NO\textsubscript{2}\textsuperscript{-}, NO\textsubscript{3}\textsuperscript{-}, PO\textsubscript{4}\textsubscript{3-}, P and SO\textsubscript{4}\textsubscript{2-} (mg*kg\textsuperscript{-1}). The CO\textsubscript{3}\textsuperscript{2-} and HCO\textsubscript{3}\textsuperscript{-} concentrations together were determined by difference between total C and organic C. Organic anions could contribute to the electrical conductivity measured but were not taken into considera-
ation for this study. The regression equations developed from the electrical conductivity and anion concentrations are presented in Table 1. The summation of all measured anions (total) resulted in a good fit ($R^2=0.92$). However, the regression

Table 1: Regression analysis of anion concentration versus electrical conductivity.

<table>
<thead>
<tr>
<th>Anion</th>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1st Order</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total (summed)</td>
<td>$y = 2.73 X$</td>
<td>0.92</td>
</tr>
<tr>
<td>$\text{NO}_3^-$</td>
<td>$y = 89.68 + 4.28 X$</td>
<td>0.91</td>
</tr>
<tr>
<td>$\text{F}^-$</td>
<td>$y = 691.4 - 77.53 X$</td>
<td>0.51</td>
</tr>
<tr>
<td>$\text{SO}_4^{2-}$</td>
<td>$y = -4.55 + 28.65 X$</td>
<td>0.50</td>
</tr>
<tr>
<td>$\text{PO}_4^{3-}$</td>
<td>$y = 204.68 - 24.43 X$</td>
<td>0.07</td>
</tr>
<tr>
<td>$\text{CO}_3^{2-} + \text{HCO}_3^-$</td>
<td>$y = 131.3 + 1.57 X$</td>
<td>0.03</td>
</tr>
<tr>
<td>$\text{Cl}^-$</td>
<td>$y = 137.76 + 2.54 X$</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>2nd Order</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{NO}_3^- $</td>
<td>$y = 65.47 + 7.0 X - 0.02 X^2$</td>
<td>0.93</td>
</tr>
</tbody>
</table>

equation for $\text{NO}_3^-$ alone also resulted in a good fit ($R^2=0.91$). Nitrate concentrations, in large part, explained the relationship between electrical conductivity of the soil and total anion concentrations. A curvilinear regression involving the $\text{NO}_3^-$ data improved the fit slightly ($R^2=0.93$). Soils with low concentrations of $\text{NO}_3^-\text{-N} (<30 \text{ mg} \cdot \text{kg}^{-1})$ were scattered above and below the regression line. The presence of $\text{PO}_4^{3-}$, $\text{CO}_3^{2-} + \text{HCO}_3^-$ and $\text{Cl}^-$ had very little impact on the electrical conductivity of the soil.

A value of 30 $\text{ mg} \cdot \text{kg}^{-1}$ $\text{NO}_3^-$ found in the soil (0-30 cm depth) would represent 120 $\text{ kg} \cdot \text{NO}_3^-\text{-N} \cdot \text{ha}^{-1}$. This is approximately the upper limit of the soil $N$ test at which $N$ fertilizer would be recommended for corn. Therefore the 3 highest data points ($\text{NO}_3^-\text{-N} > 30 \text{ mg} \cdot \text{kg}^{-1}$) were eliminated (Figure 1). The equation generated resulted in a poorer fit ($R^2=0.42$). These data suggest that electrical conductivity measurement of a soil could provide an approximate estimate of $\text{NO}_3^-$ concentration but accuracy would be poor for the purpose of predicting the $N$ requirement of a crop.

![Figure 1: Electrical conductivity versus $\text{NO}_3^-\text{-N}$](image)

Figure 1: Electrical conductivity versus $\text{NO}_3^-\text{-N}$
ARTIFICIAL BONDING IN SOIL AGGREGATES

J.A. Rombang and P.H. Groenevelt

Locating organic binding agents in natural soil aggregates by means of energy Dispersive Spectroscopy (EDS) is up until now not possible because of the low atomic weight of their constituents. Therefore, artificial aggregates were created by using a copolymer of vinyl chloride - vinyl acetate as a glue. This copolymer is "visible" by EDS because of the presence of chlorine.

The micrographs presented in Figures 1 and 2 were obtained by Scanning Electron Microscopy (SEM).

From these Figures one can see that artificial organic strings can coat a micro-aggregate (Fig.1 at a). They can also form a bond (bridge) between a clay micro-aggregate (Fig.2 at a) and a quartz grain (Fig.2 at b). The EDS spectrum of this bridge is presented in Figure 3, clearly showing the presence of chlorine.

The bridge shows two almost perfect menisci, which suggests that the copolymers were precipitated while the artificial aggregate was being dried out.

Figure 4 shows a bridge that was built by clay particles (Fig.4 at a) and calcium carbonate (Fig.4 at b), coated by the copolymer.

These observations provide insight in the role of organic substances in the architecture of soil aggregates.

Figure 1.

Figure 2.
Figure 3.

Figure 4.
Land Management
EFFECT OF DISTURBANCE OF FIELD SOIL COLLECTED AT DIFFERENT SEASONS ON MYCORRHIZAS OF CORN

M.H. Miller, W.A. Mitchell, R. Pararajasingham and T.P. McGonigle

Disturbance of soil from no-till corn fields has been found in previous studies to reduce P absorption by corn. The reduction in P absorption when the soil is disturbed has occurred invariably in 12 growth room experiments and two field experiments, and has frequently but not always been accompanied by a reduction in arbuscular colonization (AC) of the roots.

It has been hypothesized that disruption of the extraradical mycelium destroys a system that is capable of acquiring nutrients for a newly connected root system, thereby obviating the need to establish a new extraradical mycelium. This hypothesis assumes that disruption of the mycelium may, but does not always, reduce its ability to colonize roots.

Occurrence of the disturbance effect in the field on spring-sown crops indicates that the causal mechanism(s) is (are) operative following the winter period during which the soil is frozen for two to three months.

To determine the effect of disturbance of soil collected from the field at different seasons on P absorption by, and mycorrhizal colonization of, a newly developing corn root system.

Paired disturbed and undisturbed cores (20-cm dia) were collected from a no-till soybean field on July 16, 1991 when the soybean crop was in the vegetative state, on October 8, shortly after harvest, on November 14 shortly before soil freezing, in April 1992, shortly after thawing, and on May 6, just prior to planting of the subsequent crop. Cylinders were driven into the soil within the row to obtain the undisturbed core. Soil was removed from around this cylinder in three layers, pulverized to pass a 5-mm sieve, and packed to the same bulk density in similar cylinders to form the disturbed member of the pair.

Corn was grown in a growth room for three weeks in the disturbed and undisturbed cores following each field collection. Dry mass and P concentration of shoots, and arbuscular colonization of roots were determined.

Shoot dry mass and P concentration were lower in disturbed compared to undisturbed soil cores at all sampling times (Fig. 1). There was no consistent pattern related to season of sampling. The ratio of arbuscular colonization of roots in the disturbed relative to the undisturbed cores was 0.7 in the July sampling, and 0.9 in the November sampling but there were no differences for the October, November, April and May samplings (Fig. 1). Arbuscular colonization of roots grown in the disturbed cores increased from the July to November samples and were sustained at this higher level in the April and May samples (Fig. 1).

The results indicate that the effect of soil disturbance on phosphorus absorption is not related to the season in which the soil is collected, but the effect on arbuscular colonization is. One possible explanation for the lack of correspondence between the effect of disturbance on colonization and P absorption is that the disturbance effect on P absorption is not mycorrhizally mediated. However, strong evidence exists that it is. Accepting that the reduced P absorption is mycorrhizally mediated, the results are consistent with the hypothesis that disturbance affects the ability of the extraradical mycelium to acquire P independently of the effect on colonization.

The infectivity of propagules appeared to increase from the July to October samplings but remain constant at a high level through the fall and retained a similar infectivity the following spring. Disturbance markedly reduced the colonization in the July sampling but not in the Nov., April or May samplings. These results are similar to those of Addy et al. (page 55).

Taken together the results of this study and those of Addy et al. suggest that exposure to freezing does not reduce the ability of the mycelium to colonize roots. There is, however, a change in the nature of the mycelium following senescence of the host plant and/or exposure to freezing temperatures which alters its susceptibility to disturbance.

Fig. 1 Ratio of dry mass, shoot P concentration and shoot P content for disturbed vs undisturbed soils collected from the field at 5 times.
THE USE OF COVER CROPS FOR NITROGEN CONSERVATION

M.H. Miller, E.G. Beauchamp, T.J. Vyn, G.A. Stewart and J.D. Lauzon

There is increasing concern about the impact of crop production practices on the contribution of nitrate NO$_3^-$ to ground and surface water in Ontario. The main period of potential leaching in Ontario is in the fall after the crop has been harvested and in the late winter and spring before the succeeding crop is transpiring a significant amount of water. Any NO$_3^-$ present in the soil at these times is subject to leaching.

The use of cover crops has the potential to reduce this NO$_3^-$ and hence reduce leaching. The ideal cover crop would be one which absorbs NO$_3^-$ well into the fall, retains the N in organic forms through the spring and releases N after the succeeding crop is established and is absorbing N.

An experiment to evaluate the effectiveness of three cover crops was conducted on a sandy loam soil near Ayr and a silt loam soil at the Woodstock Research Station in 1990 and 1991. Two main crops, barley and winter wheat were grown at Woodstock and barley was grown at Ayr in 1990 each with three rates of nitrogen fertilizer (1/2, 1x and 2x recommended). Three cover crops, red clover, annual ryegrass, and oilseed radish were established either during growth (red clover and ryegrass) or following harvest (oilseed radish) of the barley and wheat crops. Corn was grown on all plots in 1991 to determine the amount of N released from the cover crop.

Oilseed radish produced the greatest dry matter (over 3 t ha$^{-1}$), red clover somewhat less (2.9 t ha$^{-1}$) and ryegrass the least (2.3 t ha$^{-1}$). The N content of the cover crop biomass was greatest for red clover (~60 kg N ha$^{-1}$) intermediate for oilseed radish (~50 kg N ha$^{-1}$) and least for ryegrass (~30 kg N ha$^{-1}$) but was not markedly influenced by N rate applied to the main crops.

Concentrations of NO$_3^-$-N in soil solution at the 75 cm depth at Ayr were low on the ryegrass and oilseed radish plots at all times. However, concentrations were quite high in the red clover and check plots in October and decreased to very low values by December, indicating that considerable leaching of NO$_3^-$ had occurred on these plots. Concentrations of NO$_3^-$ in the soil solution at Woodstock were low (<5 mg L$^{-1}$) at all sampling times which suggests that any excess NO$_3^-$ was being denitrified rather than leached.

The NO$_3^-$ content of the soil (0-45 cm) at several times is presented in Table 1. In September 1990 soil NO$_3^-$ was similar for the three cover crops but was greater for the check (no cover crop) indicating that the cover crops did reduce the NO$_3^-$ content. By November, the NO$_3^-$ content had been reduced considerably and was similar on all plots. This reduction in NO$_3^-$ is most likely due to a combination of leaching and denitrification. In April the NO$_3^-$ content had increased on all plots, with the greatest increase occurring on the oilseed radish. This indicates that the N in oilseed radish is released earlier in the spring than the N in the other crops. Soil NO$_3^-$ contents increased markedly on all plots, including the check by June. The red clover plots contained considerably more N than the check, indicating that N absorbed from the soil, or N fixed from the atmosphere was being released.

The N content of oilseed radish plots was somewhat greater than the check, but that of ryegrass was lower than the check throughout the
spring. This suggests that the N absorbed by the ryegrass was not being released.

The N content of corn in August of 1991 reflected closely the soil NO₃ contents in June. The N benefit (N content of corn on cover cop plot minus N content of check plot) is presented in Figure 1. Clearly, red clover provides the greatest benefit. The N benefit from red clover represents on average of 60% of the N content of red clover in October 1990. Oilseed radish provided some benefit but clearly, much of the N in oilseed radish in November was not available to the succeeding corn crop. The N benefit represents only 28% of the N content of oilseed radish in October 1990. It is likely that this N was lost by leaching or denitrification following release during the early spring.

It is clear that none of the three cover crops meet all the ideal criteria. Oilseed radish and annual ryegrass were more effective than red clover in reducing NO₃ leaching in the fall, but oilseed radish released N early in the spring, some of which appears to have been leached. Ryegrass, on the other hand, did not release the nitrogen in time for use by the succeeding corn crop. Additional fertilizer N would be required to produce the succeeding corn crop, thus increasing the potential for N leaching following harvest of the corn crop.

Table 1: Nitrate Content of Soil (0 - 45 cm) During Fall 1990 and Spring 1991.

<table>
<thead>
<tr>
<th>Date</th>
<th>Ryegrass</th>
<th>Oilseed Radish</th>
<th>Red Clover</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg NO₃-N ha⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 1990</td>
<td>14</td>
<td>12</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>November 1990</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>April 1991</td>
<td>13</td>
<td>29</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>May 1991</td>
<td>12</td>
<td>30</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>June 1991</td>
<td>37</td>
<td>55</td>
<td>98</td>
<td>45</td>
</tr>
</tbody>
</table>

1. Means of barley plots at Ayr and Woodstock and winter wheat plots at Woodstock.

Fig. 1. N benefit to corn from cover crops when different rates of N applied to preceding cereal crops.
NITROGEN AND PHOSPHORUS FERTILIZER APPLICATION FOR NO-TILL CORN

M.H. Miller, J.D. Lauzon and W.A. Mitchell

Optimum nutrient management for no-till corn production may differ from that for conventional tillage. Earlier work has suggested that current fertilizer P recommendations, which are based on research using conventional tillage, may be greater than that required for no-till corn. Research under an NSERC strategic grant has indicated that reduced soil disturbance, such as that occurs with no-till planting, results in increased effectiveness of mycorrhizal symbiosis, thus increasing absorption of soil P. This could result in a lower fertilizer P requirement for a given soil P test. In addition, placement of fertilizer phosphorus closer to the seed, which would increase early P absorption, may result in greater yield. A cross-slot planting system, developed in New Zealand, places fertilizer quite close to the seed row. In addition it causes considerably less disturbance than other no-till planting systems. Earlier preliminary tests with this system were promising.

In addition to the interest in phosphorus management, there is some indication that no-till corn will respond to a greater amount of N at planting than is currently recommended.

Experiments were conducted on two farm fields in 1992 with the following objectives.

1) To compare response to P using the cross-slot planter with that from a conventional no-till planter.
2) To determine the response of no-till corn to application of N close to the seed row at planting.

Experiments were conducted on Hartholm Farms, north of Woodstock in Oxford County on a loam soil previously in soybeans and on Moore Farms, south of Cambridge in Waterloo County on a sandy loam soil previously in corn.

Two planters were used. The Guelph planter is a modified JD7000. The dry fertilizer application system was removed. Two 2" fluted coulter were installed in front of each planting unit with a fertilizer injection blade attached. One fertilizer blade placed the fertilizer 5 cm (2") to the side of the seed and the other blade placed the fertilizer 10 cm (4") to the opposite side. Liquid fertilizer (either 10-34-0 or 28%) was distributed to the appropriate injectors by a pumping system. Fertilizer rates were controlled by a combination of pumping pressure and dilution of the fertilizer material.

The cross-slot planter, designed and constructed by Jack Rigby, comprised the cross-slot planting units obtained from New Zealand mounted on a New Idea planter. Liquid fertilizer is injected by a ground-driven pump.

The same set of treatments (Table 1) was used at both sites although the fertilizer rate varied depending on the soil test.

Supplemental N was applied post-emergence as UAN knifed in between rows to provide the same total rate of N to all treatments. Total N applied was 120 kg ha⁻¹ at Hartholm and 150 kg ha⁻¹ at Moore. At Hartholm, the 60 kg N ha⁻¹ applied as UAN broadcast with the herbicide application shortly after planting was included in the total applied.
Table 1: Treatments used at 1992 Experimental Sites.

<table>
<thead>
<tr>
<th>Trt No.</th>
<th>Planter</th>
<th>Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-1</td>
<td>Guelph</td>
<td>No fertilizer</td>
</tr>
<tr>
<td>G-2</td>
<td>Guelph</td>
<td>10-34-0 - 1/2/rec. P rate</td>
</tr>
<tr>
<td>G-3</td>
<td>Guelph</td>
<td>10-34-0 - rec. P rate</td>
</tr>
<tr>
<td>G-4</td>
<td>Guelph</td>
<td>10-34-0 + 20 kg N ha⁻¹ - narrow band</td>
</tr>
<tr>
<td>G-5</td>
<td>Guelph</td>
<td>10-34-0 + 40 kg N ha⁻¹ - narrow band</td>
</tr>
<tr>
<td>G-6</td>
<td>Guelph</td>
<td>10-34-0 + 20 kg N ha⁻¹ - wide band</td>
</tr>
<tr>
<td>G-7</td>
<td>Guelph</td>
<td>10-34-0 + 40 kg N ha⁻¹ - wide band</td>
</tr>
<tr>
<td>CS-1</td>
<td>Cross slot</td>
<td>No fertilizer</td>
</tr>
<tr>
<td>CS-2</td>
<td>Cross slot</td>
<td>10-34-0 - 1/2 rec.</td>
</tr>
<tr>
<td>CS-3</td>
<td>Cross slot</td>
<td>10-34-0 - rec.</td>
</tr>
</tbody>
</table>

Note
1) Recommended P rates - Hartholm - 70 kg P₂O₅ ha⁻¹
   Moore - 20 kg P₂O₅ ha⁻¹

2) For treatments G-4 to G-7 at Hartholm 1/2 rec. rate of 10-34-0 used; at Moore, rec. rate of 10-34-0 used.

3) 10-34-0 placed 5 cm (2") to side of seed row with Guelph planter.

4) N placement - narrow band - 5 cm to side wide band - 10 cm to side.

Grain yields were low because of the poor weather conditions. Grain yield was increased by increasing P rate with both planters at Hartholm (Table 2). There was no significant difference between planters. The highest yield was obtained with the recommended fertilizer rate. There was no response to fertilizer P rate at the Moore site which is not surprising given the soil test value (22 mg L⁻¹) and the low fertilizer P requirement (20 kg P₂O₅ ha⁻¹). Fertilizer responses are very rarely obtained with soil test values of 20 or greater.

Table 2: Grain yield as influenced by planter and fertilizer P rate.

<table>
<thead>
<tr>
<th>P Rate</th>
<th>Hartholm</th>
<th>Moore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Guelph</td>
<td>Cross-slot</td>
</tr>
<tr>
<td></td>
<td>kg/ha (bu/ac) @ 15.5% moisture</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>6008(96)</td>
<td>6309(100)</td>
</tr>
<tr>
<td>1/2 Rec.</td>
<td>6605(105)</td>
<td>6609(111)</td>
</tr>
<tr>
<td>Rec.</td>
<td>7573(120)</td>
<td>7077(113)</td>
</tr>
</tbody>
</table>

Conclusions

1) Responses to P are as would be expected given the soil tests. There is no indication of a lower than recommended P requirement. The effect of P in advancing maturity was of considerably greater importance in 1992 than in most years.

2) The cross-slot planter gave yields similar to the Guelph planter.
Grain yields at Hartholm were greatest with the 20 kg N ha\(^{-1}\) rate of additional N (Table 3). There appeared to be a reduction in yield with the 40 kg N ha\(^{-1}\) rate. This reduction, which was statistically significant only at the 0.1% level, is consistent with observed reduced early growth. The apparently greater yield at 20 kg N ha\(^{-1}\) compared to the check and 40 kg N ha\(^{-1}\) rate may be due to variation rather than a real effect. The over-all effect of N rate was not statistically significant at the 0.1% level.

At Moore farms, the 20 kg N ha\(^{-1}\) rate of additional N increased the grain yield significantly, but the 40 kg rate resulted in yields similar to those with the 20 kg rate.

**Table 3:** Grain yields as influenced by rate and placement of additional N.

<table>
<thead>
<tr>
<th>Additional N Rate(^{1})</th>
<th>Hartholm</th>
<th>Moore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Narrow(^{2})</td>
<td>Wide(^{2})</td>
</tr>
<tr>
<td></td>
<td>kg/ha (bu/ac) @ 15.5% moisture</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>6605 (105)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>7422 (118)</td>
<td>7448 (118)</td>
</tr>
<tr>
<td>40</td>
<td>6417 (102)</td>
<td>6727 (107)</td>
</tr>
</tbody>
</table>

1) N applied in addition to that supplied by 10-34-0 (Hartholm - 10 kg N ha\(^{-1}\), Moore - 6 kg N ha\(^{-1}\)).
2) Narrow - band 5 cm to side; wide - band 10 cm to side.

Conclusions

1) There was a definite response to additional N at Moore farms. At this site, which had a low soil N test (26 kg ha\(^{-1}\)), a total of 26 kg N ha\(^{-1}\) at planting (6 kg with 10-34-0 plus 20 kg additional) appeared to be sufficient. The response at Hartholm which had a much higher soil test (95 kg ha\(^{-1}\)) is less certain.

2) There was no apparent difference in response from a band placed 5 cm to the side compared to one placed 10-cm to the side of the row.

**LEACHING OF NITROGEN AND PHOSPHORUS FROM THE BIOMASS OF THREE COVER CROP SPECIES**

*M.H. Miller, E.G. Beauchamp and J.D. Lauzon*

Cover crops have a number of potential beneficial effects including reduction of erosion, improvement of soil structure and prevention of leaching of nitrate-nitrogen. However, a potential detrimental effect of cover crops, either legume or non-legume, on water quality does exist. Nutrients can be leached from the dead foliage and increase the concentration in runoff. This is of particular concern for phosphorus but also, to a lesser extent, for nitrogen. Any evaluation of the effectiveness of cover crops in reducing the impact of a cropping system on water quality must also consider this potential detrimental effect.

The quantity of a nutrient leached from plant material is dependent on four main factors: quantity of the nutrient present; mobility of the nutrient; solubility of the nutrient; and rainfall intensity and quantity. The quantity of the nutrient present in the cells is related to the plant species, age, health, and nutrient supply to the plant. Solubility and mobility of the nutrient may be increased by freezing and/or drying of the plant material.

The objective of this study was to determine the effect of freeze/thaw cycles, loading rate and rainfall intensities on the release of nitrogen and phosphorus from three commonly used cover crop species.

Plant material was collected from selected plots in a cover crop experiment conducted in 1990 and 1991 (Miller et al., p.). The field experiment consisted of three cover crops, annual ryegrass, red clover and oilseed radish interseeded in or
planted following harvest of a winter wheat crop to which either 45 or 180 kg N ha⁻¹ (1/2 and 2 x recommended) had been applied in the early spring. The cover crop biomass from a 2.25 m² area of each of three replicates of a high (180 kg ha⁻¹) and low (45 kg ha⁻¹) N treatment was collected shortly before the crop was killed by frost. Material from the three replicates was combined and frozen at -18°C and retained for leaching studies using a rainfall simulator.

Just prior to leaching, the frozen sample was thawed and a portion was allowed to dry at 30°C. The dried and undried material was leached for 45 minutes using two loading rates (2000 and 4000 kg dry mass ha⁻¹). The total leachate was collected using a sampling system which changed collection bottles at 4.5 min. intervals giving a total of 10 samples over 45 min. Following the leaching, the plant material was frozen at -18°C and a second cycle of the same treatments was conducted.

The procedure was repeated on a second sample to provide replication. There were 96 combinations of simulation situations.

Temporal Pattern of Leaching

There was considerable variability in both volume and nutrient concentrations with time during the leaching period but there were no discernible differences in temporal patterns for the different cover crops or leaching conditions. There were only small changes in concentrations of either N or P in leachate during the duration of a leaching and between leachings. The lack of marked changes in concentration in the second leaching is surprising. The samples used for the second leaching were the same ones that had been leached in the first leaching and had subsequently been refrozen. The absence of a marked decline in concentration as leaching proceeded even in the second leaching suggests that there is a release of nutrients to the leaching solution over an extended period of leaching.

Nitrogen and Phosphorus Leached

Nitrogen and phosphorous leached from the biomass of the three cover crops averaged over all treatments is presented in Table 1. Both nutrients were leached more readily from oilseed radish than from the other two crops. Nitrogen leaching from ryegrass and red clover were quite similar. However, phosphorus leached from red clover was less than that from ryegrass. This is, in part, a reflection of the lower P concentration in red clover (average of 2.1 mg g⁻¹) than in ryegrass (average of 2.4 mg g⁻¹), but the proportion of total P in red clover biomass that was leached was also lower for red clover (Table 1). Similarly, the greater P leaching from oilseed radish is due, in part, to a greater P concentration in this crop (average of 4.1 mg g⁻¹). However, a greater proportion of the total P in the biomass of oilseed radish was leached, particularly compared to red clover (Table 1).

Nutrients leached from cover crop material during the winter and spring are subject to runoff, particularly if the soil surface is frozen. The actual amount or concentrations of nutrients in runoff is dependent on the soil conditions at the time of the rainfall event. The information obtained in this study indicates the potential for contributions to surface water quality from the different cover crops, not the actual contribution.

It is of interest to compare the potential concentrations of nutrients in runoff from fields with cover crops with those from bare fields. The concentrations of nitrogen in leachates found in this study are similar to concentrations measured in runoff from bare fields. The concentra-
Table 1: Nitrogen and phosphorus leached from cover crop biomass

<table>
<thead>
<tr>
<th></th>
<th>Ryegrass</th>
<th>Oilseed Radish</th>
<th>Red Clover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>Mean Concentration (mgL⁻¹)</td>
<td>6.9</td>
<td>7.1</td>
<td>11.2</td>
</tr>
<tr>
<td>Amount Leached per Unit of Biomass (mg kg⁻¹)</td>
<td>467</td>
<td>402</td>
<td>719</td>
</tr>
<tr>
<td>Proportion of Total (%) Biomass Nutrient Leached</td>
<td>7.6</td>
<td>29.7</td>
<td>10.5</td>
</tr>
</tbody>
</table>

1. Averages for the two nitrogen rates on the wheat crop and for all leaching variables including the first and second leaching.

RELATIVE TOXICITY OF SIX LIQUID FERTILIZERS APPLIED WITH THE SEED OF CORN AND SOYBEANS

M.H. Miller, W.A. Mitchell and J.D. Lauton

Application of liquid fertilizer with the seed of corn has frequently resulted in small but profitable yield increases. Although yield increases have not been measured with soybeans, some farmers are following the practice with this crop as well.

Only low rates of fertilizer can be safely applied directly with the seed. Current recommendations (Public. 296, Ontario Ministry of Agriculture and Food) indicate that not more than 7 kg of N plus K₂O per hectare can be safely applied with the seed of corn in 100 cm rows. It is also recommended that diammonium phosphate or urea should not be applied with the seed of corn and that no fertilizer should be applied with the seed of soybeans.

Several liquid fertilizers varying in analysis and in composition are available on the market. Questions are frequently raised by farmers about the relative safety of these materials.

A greenhouse experiment was conducted to compare six different liquid fertilizers in terms of their effects on germination of corn and soybeans.

A medium-textured soil in the field moist state was placed in a 20 x 50 cm tray. Four rows of 10 seeds each were placed lengthwise in the tray and the volume of a given liquid fertilizer was pipetted onto each row to provide rates of 7.5, 15, 30 and 60 kg P₂O₅ per hectare assuming a 75 cm (30 in) row spacing for corn and a 37.5 cm (15 in) row spacing for soybeans. These rates are equivalent to 2, 4, 8 and 16 gallons of 6-25-6/acre respectively.

Following fertilizer application, the seeds were covered with soil and a layer of silica sand to reduce surface evaporation. The tray was covered with aluminum foil to reflect in-coming radiation. Replicate trays were established for each of the six liquid fertilizers. There were also two trays in which water was added at rates equivalent to the average volume of liquid in the fertilizers.

Complete emergence of corn had occurred six days after planting with all six fertilizers applied at the lowest rate. The numbers of corn plants emerged at the three higher rates are shown in Figure 1. Two materials, 3-18-18 and 9-18-9, reduced the emergence of corn at the second rate and almost eliminated emergence at the third rate. Emergence at the highest rate was reduced markedly by 8-25-3 and to a lesser extent by 6-24-6, 6-25-6 and 10-34-0. There were no significant differences amongst these latter three materials.

Soybean emergence was reduced somewhat more than corn by all fertilizer materials (Figure 2), in spite of the fact that, because of the narrower row spacing, the fertilizer
concentration in the row was only half that of corn. This indicates that soybeans are more than twice as sensitive as corn. The relative toxicity of the different materials on soybeans was very similar to that for corn.

The relative toxicity of the six materials tested is as follows:

9-18-9 = 3-18-18
which are more toxic than
8-25-3
which is more toxic than
6-24-6 = 6-25-6 = 10-34-0

The conditions under which this trial was conducted do not correspond closely enough to those in the field to permit recommendations of the actual rates that can be used safely. The study does indicate, however, that soybeans are much more sensitive than corn. Because of this and the fact that there is no evidence of a response of soybeans to fertilizer with the seed, the current recommendation that fertilizer not be applied with the seed of soybeans is justified.

![Figure 1 Corn plant emergence.](image)

![Figure 2 Soybean plant emergence.](image)

SURVIVAL OF THE EXTERNAL MYCELIUM OF VAM FUNGI IN FROZEN SOIL OVER WINTER

**H.D. Addy, G. Schaffer, M.H. Miller, and R.L. Peterson**

Vesicular-arbuscular mycorrhizae (VAM) are symbiotic associations between plant roots and soil fungi, which increase the uptake of nutrients, especially P, by plants. Fungal strands, or hyphae, of the mycorrhizae extend from the root into the soil, where they proliferate to form a hyphal network or mycelium. This external mycelium is important both as a nutrient absorption system and as root inoculum. We have hypothesized that disturbance of the soil disrupts this mycelium, reducing its effectiveness as a nutrient uptake system for a developing root system. Disruption of the mycelium may also reduce its effectiveness in colonization of roots. These negative effects of soil disturbance have been observed in spring-planted crops, suggesting that the intact mycelium remains viable over winter. A preliminary study was undertaken to investigate the question: does the external mycelium of VAM fungi survive winter freezing and act as a source of inoculum?

The first step of the experiment was to establish external mycelia in pouches, which would later be transplanted to field soil. Maize (Zea mays L.) plants were grown in soil that had been inoculated with a VAM fungal species. Two pouches of very fine nylon mesh, containing pasteurized soil, were placed in each inoculated pot prior to seeding. The pores in the mesh were imperious to plant roots, but not to mycorrhizal hyphae. After six weeks, pouches were buried in the same field at the Elora Research Station from which the soil had been collected. Pouches were removed from the field once while the soil was still frozen (March 1992), and once after the soil had
thawed (April 1992). Some pouches were maintained in the growth chamber, but were transferred to pots containing unpasteurised soil only. These unfrozen Control pouches were removed from the pots two weeks later.

At all three sampling times, soil was removed from one pouch of each pair and subsamples were taken for measurement of external hyphal length and viability, and VAM spore density. The remaining soil was disturbed by mixing and sieving, and replaced in the pouch. The soil in the other pouch of each pair was left undisturbed. Seeds of Sudan grass (*Sorghum sudanense* Staph.) were planted directly into each pouch; root colonization was determined after four weeks.

The results of this experiment suggest that at least part of the external mycelium of this VAM fungus survives winter freezing, as live hyphae were observed in samples from both frozen soil and soil sampled shortly after spring thaw.

Colonization by VAM fungi was observed in roots of all bioassay plants (Fig. 1); thus the external hyphae not only survived, but retained their ability to colonize roots. It is unlikely that VAM spores played a significant role in the colonization of bioassay plant roots, as spore density in the pouches at all three harvests was very low (1 to 5 spores g⁻¹ soil), and previous observations indicated that spores of this particular fungus have low viability.

The ratio of live to dead hyphal length was lower in samples taken from frozen soil than in unfrozen Control samples (Fig. 2). In samples taken after the soil had thawed, the ratio of live to dead hyphae had increased dramatically (Fig. 2). We also observed a change in the morphology of the live segments of hyphae over winter. The length of live segments within a hypha was greater in the unfrozen Control samples than samples taken from either frozen soil or thawed soil in the spring. In both of the latter samples, small live segments of hyphae separated by larger dead segments were observed. Extensive fine branching of the live segments was observed in the samples collected in April.

We suggest that these changes in the distribution of live cytoplasm within hyphae represents the formation of "resting hyphae", an adaptation that enables hyphae to survive winter freezing. In the spring, the live segments of cytoplasm expand, perhaps growing back through old hyphae, and branch as was observed in the thawed April samples. This pattern of growth would enable the external network to re-form quickly early in the spring.

Soil disturbance reduced root colonization of bioassay plants grown in the unfrozen Control pouches. However, disturbance did not decrease colonization of plants grown in pouches from either frozen soil or soil after spring thaw. Recent research by Miller et al. (see this Report, page 47) has also shown a seasonal effect of soil disturbance on root colonization.

We hypothesize that this seasonal effect of disturbance may be, at least in part, related to the transformation of external hyphae into "resting hyphae" in response to cold temperatures. In this transformation, the live cytoplasm is divided into discontinuous fragments within hyphae; thus soil disturbance would not be disrupting an intact hyphal network, and root colonization would not be significantly reduced.

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![Figure 1. Corn plant emergence.](image1)

![Figure 2. Soybean plant emergence.](image2)
ROLE OF COLLEMBOLA (*Folsomia candida* Willem) IN SOIL ORGANIC MATTER DECOMPOSITION: EVIDENCE OF GRAZING, DISPERSAL AND COMMINUTION

Z. Zhang and P. Voroney

Fauna make only a small direct contribution to the total respiratory metabolism (< 10%) in soils. However, they can act as an important regulator of decomposition processes through their interactions with the soil microflora. These interactions consist of: (i) dispersal of microbial propagules, (ii) grazing on microflora, and (iii) comminution and mixing of plant residues. While each of these interactions has been demonstrated in field and laboratory studies, their significance in organic matter (OM) decomposition is not well understood. The objectives of this research were to assess the nature and magnitude of the activities of collembola (*Folsomia candida* Willem), a common soil animal, on (OM) decomposition. These experiments were conducted in microcosm systems where a sterilization treatment was used to reduce the size and complexity of the soil microfloral population, and numbers of collembola were varied. Soils were amended with 14C-labelled substrates, glucose, corn grain and corn stover, and measurements of 14C-CO₂ evolution and 14C-microbial biomass were made during incubations lasting up to 8 weeks.

Collembola could either significantly enhance or depress 14C-CO₂ evolution depending on the nature of the substrate and on the inoculum potential of the soil microbial population (Fig. 1a, 1b and 1c). Under conditions where the soil microbial population had been reduced by a sterilization treatment, collembola significantly reduced the daily mineralization rates of corn grain and stover. Unlike glucose which is easily assimilated by most microorganisms, both stover and grain are

![Figure 1a](image1a.png) **Figure 1a** Collembolan effects on the daily rate of CO₂ evolution in the soils amended with glucose.

![Figure 1b](image1b.png) **Figure 1b** Collembolan effects on the daily rate of CO₂ evolution in the soils amended with corn grain.

![Figure 1c](image1c.png) **Figure 1c** Collembolan effects on the daily rate of CO₂ evolution in the soils amended with corn stover.
relatively difficult to decompose. Thus, the activity of collembola during the early stages of decomposition could significantly delay and reduce composition of complex and insoluble substrates by limiting and production and dispersal of microbial propagules. Collembola decreased the cumulative $^{14}$C-CO$_2$ evolved during corn stover decomposition by 17%. Grazing of microbiota by collembola can be an important activity at later stages of decomposition. This is likely caused by collembola promoting the decomposition of microbiota which have developed with addition of substrate. Grazing effects were evident in all treatments in which the soil population had been reduced by a sterilization treatment. Collembola increased the cumulative $^{14}$C-CO$_2$ evolved during glucose and corn grain decomposition by 10% and 6%, respectively.

The comminution activity of collembola may be responsible for enhancing decomposition of specific substrates, as was noted in the experiment with unsterilized soil receiving corn grain. Daily rates of $^{14}$C-CO$_2$ evolution were significantly greater during the 14 to 28-day period of the incubation in the treatment with collembola. This may be evidence for the selective feeding behaviour of collembola, which made the grain corn more available to microbial attack by reducing its particle size. This research confirms the significant potential role of collembola, largely through its interactions with the microbiota. While the effects of collembola may not always be detected because their direct contribution to CO$_2$ evolution is small, where the substrate added to soil is complex and difficult to decompose or the microbial inoculum potential is low they may be of profound importance in regulating organic mafter decomposition.

EFLLUX OF TRACE GREENHOUSE GASES FROM AGRICULTURAL SITES INTO THE ATMOSPHERE


Increases in concentration of greenhouse gases in the atmosphere are expected to bring about global climate change. The objectives of this project is to understand the effect of agricultural production practices on emission and uptake of the most important greenhouse gases: nitrous oxide (N$_2$O), methane (CH$_4$) and carbon dioxide (CO$_2$). In this study, we report nitrous oxide and methane fluxes measured using micrometeorological techniques and a new trace gas sensor based on tunable diode laser (TDL) spectroscopy, developed at the University of Guelph. Background N$_2$O and CH$_4$ fluxes from various agricultural fields (bare soil, bare soil treated with manure, alfalfa and grass), as well as fluxes occurring after manure applications are presented. CO$_2$ flux from bare soil and uptake by the alfalfa crop were also measured.

In 1992, one bare soil plot was used as a control plot, while the other was treated with liquid dairy cattle manure on May 13 (day 134), and on August 26 (day 239). Both bare soil plots were cultivated after each manure application. Alfalfa was planted on May 12 (day 133), cut and removed from the plots on August 12, 1992 (day 225). Estimates of alfalfa dry matter from sampling of plants on cutting day were 590 kg ha$^{-1}$ for roots and 2100 kg ha$^{-1}$ for tops. The Kentucky bluegrass was a well established 20-year old plot, to which nitrogen fertilizer was applied in the spring, and which was mowed at the end of October, 1992. Above ground grass dry matter on September 2 (day 246) was estimated as 4300 kg ha$^{-1}$. Soil cores were collected at least weekly from May 12 to November 25, 1992. Occasionally soil core sampling was done more often when it was anticipated that episodic events of N$_2$O production or denitrification would occur.

The average N$_2$O flux for the spring of 1992 (31.1 ng m$^{-2}$ s$^{-1}$), was not significantly different from the emissions measured in 1991 excluding fluxes measured after the addition of sucrose (24.4 ng m$^{-2}$ s$^{-1}$). Daily averages were also variable, and associated with natural events (Figure 1). But, measurements of fluxes during the summer and fall of 1992 (Figures 2) indicated limited emissions with seasonal daily averages (3 ng m$^{-2}$ s$^{-1}$) that were significantly lower than spring emissions. It is likely that a prolonged period of fallow without the addition of any fertilizer or organic carbon (from October of 1991 to July 1992) could have resulted in limiting levels of NH$_4^+$, NO$_3^-$, and/or organic carbon. But, preliminary inspection of nitrate and ammonium levels in the bare soil plot indicated no marked difference with bare soil plots treated with manure. Also, the
occurrence of cool temperature and above normal rainfall during this past summer limits the extrapolation of the obtained results.

Differences between the cropped plots and the bare soil plot were not detected (Figure 2). Significantly higher $\text{N}_2\text{O}$ and $\text{CH}_4$ emissions from the bare soil treated with manure were mainly associated with the manure application on day 239. The alfalfa cutting event did not significantly affect fluxes from that plot. The $\text{CO}_2$ flux from the alfalfa plot was affected by cutting. There was a net downward flux from the atmosphere to the crop of about 0.25 mg m$^{-2}$ s$^{-1}$ for the 10 days prior to cutting, but about 0.01 mg m$^{-2}$ s$^{-1}$ $\text{CO}_2$ flux from the crop for 10 days after cutting. The $\text{CO}_2$ emissions from the bare soil plot throughout the summer were generally in the range of 0.05 to 0.10 mg m$^{-2}$ s$^{-1}$ and averaged about 0.06 mg m$^{-2}$ s$^{-1}$. Continuation of measurements in 1993 will provide additional data and contribute to the interpretation of these results.

The relationship of $\text{N}_2\text{O}$ production from soil cores with three primary soil parameters namely soil water content, organic C supply and $\text{NO}_3^{-}$ content was often complex and dependent on the presence or absence of a crop. For example, it was often observed that substantial $\text{N}_2\text{O}$ production occurred in spite of an apparent absence of $\text{NO}_3^{-}$ in the grass and alfalfa plots. In other plots without a crop, $\text{N}_2\text{O}$ production was often nil or very low in spite of the presence of high $\text{NO}_3^{-}$ levels. The respective roles of nitrification and denitrification with these observations was not clear although C substrate supply and soil water content were also involved. In many weekly data sets soil $\text{NH}_4^{+}$ concentration seemed to be positively related to $\text{N}_2\text{O}$ production. Although not observed in previous studies, this relationship probably reflected the nitrification of $\text{NH}_4^{+}$ with $\text{N}_2\text{O}$ production. $\text{N}_2\text{O}$ production was often observed to be generally related to extractable organic C although there was usually a wide scatter of data points. It was noted that 30-50 mg ext C/kg soil was not available to soil microbes involved with $\text{N}_2\text{O}$ production or denitrification.

In conclusion, a prolonged fallow period resulted in limiting conditions for nitrous oxide emissions from a bare soil, possibly related to a decrease in available organic carbon. But, the nitrous oxide and methane emissions from a bare soil plot increased significantly after a manure treatment. The presence of crops (alfalfa and bluegrass) did not significantly affect nitrous oxide or methane emissions.

Figure 1. Daily average $\text{N}_2\text{O}$ fluxes measured over bare soil at Elora during the spring of 1992.

Figure 2. Daily average $\text{N}_2\text{O}$ fluxes measured over bare soil, bare soil treated with manure, alfalfa and grass plots at Elora during the summer of 1992. Arrows indicate the timing of alfalfa cutting and of manure application.

Figure 3. Daily average $\text{CH}_4$ fluxes measured over bare soil, bare soil treated with manure, alfalfa and grass plots at Elora during the summer of 1992. Arrows indicate the timing of alfalfa cutting and of manure application.
FORAGE QUALITY AS AffECTED BY WEATHER DURING FIELD DRYING FOR HAY

D.M. Brown and A.G. Barr

Sampling of forages in the swath during field drying to determine changes in quality caused by wet weather for the SimForQ (Simulation of Forage Quality) model validation, continued in 1992. Samples were collected from replicated swaths for all three growth cycles (Cuts 1, 2 and 3) at the Elora R.S., for Cuts 1 and 2 at New Liskeard, and for separate fields of alfalfa and grass at time of first Cut at Kemptville. Wet weather occurred following all three cuttings at Elora and following Cut 2 at New Liskeard. As a result the forage was sampled for periods of 9 to 12 days, during which considerable deterioration in quality of hay occurred. Moisture content at time of each sampling and quality of forage based on Acid Detergent Fibre, Neutral Detergent Fibre and Crude Protein were determined. In addition, samples were collected from first cut forage at ERS for preliminary counts of microbial populations.

Some changes were made to the SimForQ model based on discussions with personnel in Michigan and Wisconsin, who are associated with the National Dairy Forage Laboratory. These changes include:

- forage quality levels at time of cutting;
- addition of a second equation for estimating Digestible DM from ADF for second and third growth cycle forage;
- a new equation for estimating DDM from ADF for forage grasses, e.g. timothy;
- proportioning respiration losses caused by microbial activity with those for plant respiration.

Comparisons of SimForQ model output with field results from 1992 measurements resulted in the following conclusions:

1. An improved forage drying subroutine is required for SimForQ;
2. Crude protein levels used for input for freshly cut forage in SimForQ appear to be 2 to 5% too high for all three cuttings, although the change in protein level during drying is estimated quite well.
3. The levels of ADF and NDF for fresh cut forage at different stages of development that were derived for Cut 1, based on the Guelph growth curve experiments conducted in the early 1960’s, are adequate for alfalfa and grass varieties grown today. The new relationships for Cuts 2 and 3 based on a study at Michigan State University provide levels of ADF and NDF that are too low for freshly cut forage.
4. Increases in ADF and NDF (decrease in forage digestibility and intake by livestock) as modelled by SimForQ are slightly less than measured values during extended wet periods before the introduction of losses caused by microbial respiration. After the introduction of a subroutine for microbial losses, the model increased ADF and NDF more than measured in 1992, whereas the increase was slightly less than measured in 1991.

The graphs in Figure illustrate the following points:

(a) drying subroutine in SimForQ dries forage too rapidly especially below 45% forage moisture content;
(b) estimates of ADF increase are less than measured when modelled moisture content used to estimate change in quality during drying;
(c) estimates of ADF increase are improved when measured daily moisture content and measured initial ADF level are used as model input;
(d) estimates of ADF increase are too large when microbial respiration losses are introduced as a subroutine in SimForQ.

These results are an example of the output results obtained from the modified SimForQ when compared to field measurements in 1992. Further validation comparisons and modifications in SimForQ are required before it can be used as a tool for estimation of forage quality losses during field drying for hay.
SIMULATION OF LEAF SURFACE WETNESS EFFECTS ON RADAR BACKSCATTER USING THE MIMICS MODEL

L.X. Wang, T.J. Gillespie, R. Protz and G.E. Kidd

Research with ground-based scatterometer data and airborne synthetic aperture radar (SAR) data has demonstrated changes in radar backscatter due to the presence of surface wetness (dew and rain) on some agricultural crops. This report outlines results of surface wetness simulations using the University of Michigan’s Microwave Canopy Scattering Model (MIMICS) for spring wheat crops. The canopy regions considered were the soil, wheat stems, wheat leaves, and elements made of pure water in various geometric shapes. We used long, thin parallel water cylinders to model rows of dew drops because this geometric shape is a readily available choice in the MIMICS program. Short, randomly-distributed water cylinders (0.8 x 1.5cm in size chosen to give sufficient backscatter) at various spatial densities were used to represent rain droplets captured on leaf surfaces.

For the dew simulation, only the leaf surface water was changed. We began to add "dew cylinders" to leaves about midnight, increased the number of cylinders until about 05:00 (near sunrise), then slowly removed the water cylinders until 08:00. The soil moisture was held constant for this simulation.

For the rain simulation, we found it necessary to consider both plant surface wetness and soil moisture for two reasons. First, the soil moisture is likely to change much more significantly during a rain event than during a dew event. Second, dew often covers most of a leaf and therefore presents a target of similar size to the leaf itself, while raindrops sit at discrete locations on the leaf surface, thus presenting smaller targets. This may reduce the contribution of raindrops to backscatter (depending on radar wavelength), thus enhancing the soil contribution.

These simulations which use the MIMICS model to quantify the effects of surface water on radar backscatter are promising. Dew was quite successfully simulated in C-band as a covering of long, horizontal water cylinders. Rain simulations in K-band showed strong response to leaf droplets, L-band was dominated by soil moisture, and C-band showed significant contributions from both leaf droplets and soil wetness. These differences are likely due to interactions between water target size and radar wavelength.
Two related preliminary studies have been conducted in conjunction with Oxford Agropro Ltd., our industry partner. The spatial variability of P and K soil fertility on three sites in southwestern Ontario was characterized to examine the implications of this variability to the use of a computer controlled variable rate fertilizer spreader. Topography affects the distribution of soil properties (Gerrard, 1981) and hence, the influence of topography on P and K soil fertility and on a variable rate fertilization program for these sites was examined.

Transect and grid soil sampling and soil test analysis were conducted on sites chosen for a high degree of soil fertility variability. The grid soil fertility data at each site was rigged and then grouped into four to five areas having similar fertility requirements, utilizing software proprietary to the variable rate spreader.

Digital topographic analysis was conducted on a 10 m by 15 m grid basis using a modification to the computer program GEOM1 (Boundy and Martz, 1988) that added landform classification according to the criteria of Pennock and de Jong (1987) and a simplified landform classification at selected topographically equivalent benchmarks (Fig. 1). The benchmarks chosen delineate and characterize the major differences in topography on these sites.

Spatially variable fertilizer application would apply more fertilizer in total at two sites, but would apply it only on areas with greater fertilizer requirements. This could improve crop fertilizer-use efficiency. At the Llowns site, soil test P was greater at the level-N and footslope benchmarks than at the backslope. Soil test K values were greater at the level-N, level-S, shoulder and backslope benchmarks than at the footslope. At the Hammertons site, soil test K values were greater at the lower footslope benchmarks than at upper footslope or shoulder benchmarks. If fertilizer were applied on a basis of the grid soil test analysis, then at the Llowns site, the backslope benchmarks would receive more P fertilizer than the level benchmarks. Backslope, shoulder and footslope benchmarks would receive more K fertilizer than the level benchmarks. There would be no significant relationship between topography and fertilizer applied at the other two sites. At the Llowns site variable rate fertilizer application on a basis of grid soil test analysis would be similar to application on a basis of soil test variation with topography. Deriving agronomic and environmental benefit from variable rate application technology will require consideration of band application of P, determination of a practical basis on which to apply N variably, P and K added with "starter", management of the extra time and cost constraints associated with variable application, and the limitations to yield potential imposed by soil factors other than fertility.
CLEANING UP THE MILKHOUSE WASTE WATER DISPOSAL MESS

M. Anderson and P.H. Groeneveld

The literature relating to the failure of household weeping bed systems, as well as a preliminary laboratory study, indicate that the volume of milk entering the disposal system would be the critical factor affecting the lifespan of a weeping bed system. Essentially there are two sources of milk entering these systems:

1) Day to day residual milk from the milking equipment
2) Milk spills

RESIDUAL MILK INPUT MEASUREMENTS

Measuring the volume of residual milk left in the milking system was of considerable interest since it would determine the amount of milk entering the disposal system if the first rinse was not diverted.

A representative sample of the pipeline rinse water was taken on 15 farms following milking. The total volume of the water used for pipeline rinsing was measured either manually or with previously installed water meters.

The milk concentration of this sample was determined using a Sybron PC700 colorimeter at a wavelength of 620nm. This instrument measures the optical absorbance of a liquid sample. The optical absorbance measurement was used to arrive at the percentage milk by a characterization curve determined from a composite sample of the milk from five different farms. This curve and equation are given in Figure 1.

![Figure 1: The volume of milk measured in the rinse water of 15 farms averaged 5.86 litre/day.](chart)

SEGREGATING MILK INPUTS

The literature relating to the functioning and failure of weeping bed systems showed that the loading of organics as measured by BOD and TSS were a primary cause of soil clogging and system failure.

It has been shown that the segregation of the problem components of wastes before they entered the disposal system greatly reduced soil clogging. The BOD in milkhouse wash water is almost completely restricted to the rinse cycle since this removes over 90% of residual milk from the milking pipelines and apparatus. This principle is particularly critical in this case since whole milk has an extremely high BOD value of approximately 100,000 mg/L. It can now be seen that the segregation of problem wastes in milkhouse wash water is very simple since virtually all the organics are in the form of milk and this milk is almost entirely confined to the rinse cycle.

MILK SPILLS

The accidental or intentional dumping of milk from the bulk tank is another source of milk entering the septic system and a probable cause of system failure. These spills are usually on the order of 200-500 L of whole milk. Accidental dumping is usually a result of a farmer forgetting to replace the drain plug on the bulk tank after washing. During the next milking, milk drains out of the tank and into the septic system.

THEORETICAL MODEL OF MILK INPUTS

It is important to note the relative importance of rinse and spill inputs of milk into the weeping bed system. A theoretical model was developed to illustrate this and is shown in Figure 2.

The slope of line A represents a farm in which the average daily milk input of 5.86 litres/day (the average residual milk volume of 15 farms) was entering the treatment system each day. The slope of line B represents a farm which was pre-rinsing the lines and feeding this milky water to calves rather than allowing it to enter the treatment system but had a 600 litre milk spill three years after installation. The slope of line B corresponds to 0.5 litres of milk/day entering the treatment system.
As can be seen in Figure 2, farm A will reach this line after only 5 years whereas farm B in spite of a 500 litre spill will continue to function long into the future.

**POTENTIAL BENEFITS OF PRE-RINSING**

From these principles we hypothesize that the practice of diverting the first pipeline rinse water will have the following benefits:

- Greatly increase the reliability and useful lifespan of milkhouse septic systems which are still functioning or yet to be installed.
- Reduce the risk of system failure in the case of an accidental or intentional milk spillage into the septic system.
- Make it possible to re-use those systems which have failed and been abandoned for more than one year. Failed household weeping beds which have been abandoned for 8-12 months have been found to restore themselves to near original infiltrative capacities. These systems might be re-used successfully if daily milk inputs from rinse water were eliminated.
- Potentially allow for the successful operation of milkhouse septic systems on soil types which were previously considered too heavy.
- Provide a potential solution to this problem which is both simple and inexpensive, and therefore readily acceptable to the farming community.

**GROUNDWATER QUALITY, MEASUREMENT AND PREDICTION**

*M.J. Goss, P. Smith, D. Barry, D. Goorahoo*

Agriculture Canada recently sponsored a major survey of groundwater quality in Ontario "The Ontario Farm Groundwater Quality Survey". The first sampling programme, carried out in winter 1991/92, was designed to evaluate the rural groundwater conditions in Ontario at a provincial scale. This objective was approached through a single sampling of farm wells, and by sampling a limited number of wells with ports at different depths specially installed in fields and woodlots. Confirmation of the results and clarification of information about the impact of agricultural practices on groundwater quality was sought in a second sampling carried out in July 1992.

Results from the first sampling highlighted the contamination of wells by bacteria commonly associated with faeces. More than 30% of farm wells contained coliform bacteria in excess of the limits specified in the drinking water objectives, and 20% contained faecal coliforms. Nitrate contamination was also found in 13% of wells. Pesticides were not found to be major contaminants. The second sampling showed a 6% increase in the average (geometric mean) concentration of nitrate in wells in the province. The general frequency of contaminated wells (nitrate and bacteria) showed a small rise. There was a close correlation between the wells contaminated by nitrate in the first round of sampling, and those contaminated in the second round. Many wells not contaminated with bacteria in the
first round were found to be contaminated in the second round, indicating the dynamic nature of the contamination.

These results confirmed that the nitrate contamination was widespread and persistent, and indicate that long-term solutions are needed to reduce groundwater contamination. The significance of septic systems and other point sources of nitrate and bacteria for contamination of groundwater on farms also needs to be clarified.

One approach to finding a solution is to assess farming systems for any that might result in a reduction in the general level of contamination. A potentially useful method for predicting losses of nitrate from agriculture to groundwater is to calculate the nitrogen balance for a whole farm, taking account of animals and crops. The resultant N-budget can be formulated so that a positive balance indicates the amount of N potentially available for leaching. This amount for typical farming systems could then be combined with hydrological information and climatic data using a Geographic Information System to predict maximum nitrate-N concentrations moving to groundwater from farming in the region. The basic relationships for the nitrogen budget of a farm can be summarized as:

\[ \text{nitrogen in inputs} = \text{nitrogen in output} + \text{change in the nitrogen contents of the soil, livestock and other components}. \]

Calculation of an N budget can be simplified by assuming that there is no net change in the nitrogen content of farm assets. Thus for an arable farm it is assumed that soil organic matter content, and consequently soil N content, remain constant on a yearly basis for monoculture systems or over the course of a rotation when a sequence of crops are grown.

Similarly for a livestock operation it is assumed that the number of animals and their demography remain constant. The N-budget for one cycle of the farming system, either one year or the length of a crop rotation can then indicate the long term potential of a given farming system to cause nitrate-N contamination of groundwater.

The main components of the nitrogen inputs to agricultural systems are derived from direct purchases from off-farm suppliers (eg animals, seed, fertilizers and feed), and from natural processes that occur during the growth of crops (eg symbiotic nitrogen fixation) or from natural processes that are influenced by anthropogenic activity (eg atmospheric deposition).

Fertilizer inputs can be obtained from agricultural statistics on a county basis, or farmer records can be used for a whole farm, or some farmers even record inputs on a field by field basis. Average nitrogen contents of animal manures (solid or liquid) are being used in this study to convert weights or volumes of organic fertilizer applied to fields to an equivalent weight of nitrogen. The nitrogen content of seeds used in crop production can be determined from average contents published by analysts together with statistical or farmer data on seeding rates. Feed contents can be determined in the same way. The nitrogen in animals bought in can be estimated from average weights of cattle, pigs or poultry typically purchased for fattening, breeding or milking, and assuming typical values for protein content.

Natural inputs through symbiotic nitrogen fixation need to be estimated from empirical relationships between plant/crop growth and nitrogen fixed. A relationship used for grain legumes has been developed from a literature review including unpublished information from D.J. Hume (Department of Crop Science). The value used for alfalfa hay was obtained in the same way, except the best regression obtained used the extra yield of hay gained in the presence of the legume compared with the yield of unfertilized grass. An average yield for unfertilized grass of 3.2 t ha\(^{-1}\) is currently assumed.

The value used for atmospheric deposition was also obtained from the literature. Wet deposition in precipitation and mist was estimated at 10.4 kg N ha\(^{-1}\). Dry deposition in dust and other particulate material plus gaseous absorption was estimated at 8 kg N ha\(^{-1}\).

The main components of the nitrogen outputs from agricultural systems are derived from direct sales of plant and animal materials, and from gaseous and leaching losses. Sales of nitrogen are calculated from the crude protein content or nitrogen concentration of materials, and the weight of the material. Gaseous losses are assumed to be zero except for volatilization of ammonia from organic manures used or produced on the farm. Loss from animal manures is estimated to be 39% of the total manure nitrogen. Loss from sewage sludge is assumed to be 5% of total nitrogen.

The budgets are formulated to calculate the excess nitrogen on the farm at the end of a crop cycle. This weight of nitrogen is assumed to be susceptible to leaching. The annual through drainage is calculated from examination of stream discharge over the province and is currently estimated to be 160 mm.

Nitrogen budgets for some 400 farms are currently being prepared, and results compared with the nitrate-N found in the farm well supplying drinking water, or in the well installed during the ground-
water quality survey.
We have identified one cash crop farming system where there was a true balance. The rotation included corn soybeans and wheat, with two years of soybean always being grown before corn. No nitrate was found in the well, and none was predicted.

The results so far available indicate that the use of a simplified budgetary approach has considerable potential for assessing possible environmental contamination from farming systems and individual practices. Good agreement between prediction and measurement is possible when N inputs are well quantified. However, there is a less good prediction of nitrate contamination under livestock systems which needs closer examination. Similarly there is insufficient information for gaseous losses to be predicted reliably.

THE BEHAVIOUR OF PHOSPHORUS AND POTASSIUM IN IRRADIATED, COMPOSTED SEWAGE SLUDGE AND COMPOSTED MANURE


Sewage sludge is a phosphorus rich material which has been considered as P fertilizer. The P content in sewage sludge has been increasing, because more and more chemicals (FeCl₃ & AlSO₄) are added to reduce soluble P concentration in sewage effluent to prevent excess P into natural water. Inorganic phosphates are the dominant components of P in sludge and iron and aluminium phosphates usually are not highly available to crops. In this research, phosphorus availability was compared in digested sewage sludge DSS, irradiated sewage sludge DISS, irradiated and composted DICSS and composted livestock manure CLM with control treatment CT which had no P applied in a field experiment for two years. The results of analysis of the waste materials are presented (Table 1).

Table 1. The Characteristics of Organic Wastes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>1990</th>
<th></th>
<th></th>
<th></th>
<th>1991</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DSS</td>
<td>DISS</td>
<td>DICSS</td>
<td>CLM</td>
<td>DSS</td>
<td>DISS</td>
<td>DICSS</td>
<td>CLM</td>
</tr>
<tr>
<td>Phosphorus P</td>
<td>%</td>
<td>1.17</td>
<td>1.62</td>
<td>1.19</td>
<td>0.64</td>
<td>3.18</td>
<td>3.63</td>
<td>2.19</td>
<td>0.36</td>
</tr>
<tr>
<td>NaHCO₃ extr.P</td>
<td>mg kg⁻¹</td>
<td>650</td>
<td>650</td>
<td>610</td>
<td>2010</td>
<td>300</td>
<td>300</td>
<td>550</td>
<td>2500</td>
</tr>
<tr>
<td>Potassium K</td>
<td>%</td>
<td>0.10</td>
<td>0.17</td>
<td>0.30</td>
<td>1.47</td>
<td>0.20</td>
<td>0.27</td>
<td>0.44</td>
<td>1.27</td>
</tr>
<tr>
<td>Calcium Ca</td>
<td>%</td>
<td>2.50</td>
<td>2.23</td>
<td>1.40</td>
<td>0.40</td>
<td>4.11</td>
<td>4.30</td>
<td>3.13</td>
<td>0.37</td>
</tr>
<tr>
<td>Aluminium Al</td>
<td>%</td>
<td>4.53</td>
<td>4.56</td>
<td>0.93</td>
<td>0.52</td>
<td>0.75</td>
<td>0.81</td>
<td>0.61</td>
<td>0.49</td>
</tr>
<tr>
<td>Iron Fe</td>
<td>%</td>
<td>6.06</td>
<td>6.01</td>
<td>13.5</td>
<td>8.05</td>
<td>23.7</td>
<td>23.8</td>
<td>24.5</td>
<td>5.58</td>
</tr>
</tbody>
</table>

All analyses except dry matter are on a dry weight basis.

Nitrogen and potassium fertilizers were added to the soil where required to provide recommended rates of application to make the comparison at fairly equal basis. In the first year, although NaHCO₃ extractable P was very low in DSS, DISS and DICSS wastes, the P concentration in lettuce, which was grown for 5 weeks right after waste applications, increased by all wastes sources (Table 2). (In the following tables means not followed same letter are significant different at 0.05 level).
Table 2. P Concentration in Lettuce Leaves (1990)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>CT</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSS</td>
<td>7.08</td>
<td>7.01</td>
<td>6.93</td>
<td>6.63</td>
<td>6.91a</td>
<td></td>
</tr>
<tr>
<td>DISS</td>
<td>6.96</td>
<td>6.54</td>
<td>7.05</td>
<td>7.29</td>
<td>6.96a</td>
<td></td>
</tr>
<tr>
<td>DICSS</td>
<td>7.04</td>
<td>6.94</td>
<td>6.79</td>
<td>6.95</td>
<td>6.93a</td>
<td></td>
</tr>
<tr>
<td>CLM</td>
<td>7.70</td>
<td>6.99</td>
<td>7.60</td>
<td>7.15</td>
<td>7.36b</td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td>6.31c</td>
<td>7.20</td>
<td>6.87</td>
<td>7.09</td>
<td>7.01</td>
<td>7.04</td>
</tr>
</tbody>
</table>

C.V.% = 7.2  L.S.D.(0.05) = 0.72

For crops with longer time growth periods in the field, there was no P fertilization effect on plant P with any of wastes application (Table 3).

Table 3. P Concentration in Petunia (1990)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>CT</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSS</td>
<td>3.68</td>
<td>4.00</td>
<td>3.96</td>
<td>3.80</td>
<td>3.95</td>
<td></td>
</tr>
<tr>
<td>DISS</td>
<td>3.93</td>
<td>3.84</td>
<td>3.95</td>
<td>4.09</td>
<td>3.91</td>
<td></td>
</tr>
<tr>
<td>DICSS</td>
<td>3.83</td>
<td>3.96</td>
<td>3.91</td>
<td>3.94</td>
<td>3.87</td>
<td></td>
</tr>
<tr>
<td>CLM</td>
<td>3.79</td>
<td>4.13</td>
<td>3.79</td>
<td>3.78</td>
<td>3.86</td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td>3.90</td>
<td>3.80</td>
<td>3.98</td>
<td>3.90</td>
<td>3.90</td>
<td>3.89</td>
</tr>
</tbody>
</table>

C.V.% = 6.48

In 1991, the concentration of total Fe and Al were higher in DSS and DISS than these in 1990 while the concentrations of the NaHCO₃ extractable P were much lower. The application of these wastes did not significantly increase P concentration in lettuce compared with CT (Table 4).
Table 4. P Concentration in Lettuce Leaves (First Cut, 1991)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>Application Rate (Mg ha⁻¹)</th>
<th>CT</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>*Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSS</td>
<td>5.05</td>
<td>4.93</td>
<td>4.99</td>
<td>4.48</td>
<td>4.99a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISS</td>
<td>5.11</td>
<td>4.90</td>
<td>5.10</td>
<td>4.50</td>
<td>5.03ab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DICSS</td>
<td>5.39</td>
<td>5.37</td>
<td>5.34</td>
<td></td>
<td>5.36bc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLM</td>
<td>5.47</td>
<td>5.41</td>
<td>5.40</td>
<td>5.83</td>
<td>5.43c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*MEAN</td>
<td>4.70a</td>
<td>5.25</td>
<td>5.15</td>
<td>5.20</td>
<td></td>
<td>5.20</td>
<td></td>
</tr>
</tbody>
</table>

C.V.% = 7.84  L.S.D.(0.05) = 0.68
*Means do not include 40 Mg ha⁻¹ rate.

The high concentration of total Fe and Al in sludges and sludge compost is considered to be responsible for the lower NaHCO₃ extractable soil P (Table 5).

Table 5. The NaHCO₃ Extractable Soil P After Two Years Application.

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>Application Rate (Mg ha⁻¹)</th>
<th>CT</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>*Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg L⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSS</td>
<td>56.8</td>
<td>56.3</td>
<td>59.8</td>
<td>60.8</td>
<td>57.9a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISS</td>
<td>55.5</td>
<td>56.0</td>
<td>55.3</td>
<td>57.5</td>
<td>55.6a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DICSS</td>
<td>56.3</td>
<td>61.5</td>
<td>58.0</td>
<td></td>
<td>58.6a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLM</td>
<td>60.5</td>
<td>68.0</td>
<td>66.8</td>
<td>74.3</td>
<td>65.1b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*MEAN</td>
<td>65.3b</td>
<td>57.3</td>
<td>60.4</td>
<td>59.9</td>
<td></td>
<td>59.2</td>
<td></td>
</tr>
</tbody>
</table>

C.V.% = 10.4  L.S.D.(0.05) = 10.22
*Means do not include the 40 Mg ha⁻¹ rate.

No difference was found in plant P or soil P due to sludge irradiation. Among the wastes, CLM contained the least total P but the highest NaHCO₃ extractable P concentration. The crops grew on CLM applied soil often had the higher P concentration and after two years of application the soil NaHCO₃ extractable P was the highest.

Most of the K in the wastes was readily available. The content of K in manure was high. Sludge K content was low, because most of the K would be in the effluent. However, at the high rates of application, sludge probably can provide adequate K by itself.
FIELD EVALUATION OF NITROGEN AVAILABILITY IN IRRADIATED, COMPOSTED SEWAGE SLUDGE AND COMPOSTED MANURE

G. Wen, T.E. Bates and R.P. Voroney

Land application of suitable organic wastes is encouraged as it provides organic matter and plant nutrients to crops and is therefore an attractive alternative to waste disposal. Nitrogen availability in organic wastes is difficult to estimate accurately. Pathogenicity is a major concern when sludge is applied to crop land. Irradiation is a recognized Process to Further Reduce Pathogens method after sludge digestion. Composting is another way to eliminate pathogens which also stabilize organic matter and reduces the mass, volume and moisture content. The effects of irradiated and composted sludge on crop production have not been directly compared.

A field experiment was conducted for two years to investigate N availability in sewage sludge and composts. Four organic wastes: Digested Sewage Sludge (DSS); Irradiated Sludge (DISS); Irradiated Composted Sludge (DICSS) and Composted Livestock Manure (CLM) were applied at the rates of 10 to 40 Mg ha\(^{-1}\) year\(^{-1}\). Chemical N fertilizer was added where required to meet crop N requirement (Fig.1 & 2).

Lettuce, petunias and beans were grown during the first year and two cuts of lettuce were harvested in the second year. The availability of N in wastes was assessed by studying crop yields and crop N concentration.

The results indicated application of DSS increased crop yields (Table 1) or increased crop N concentration (Table 2) in comparison with DISS. (Means not followed same letter are significant different at 0.05 level and L.S.D. is used for comparison of individual treatment in the tables).

Table 1. Yield of Petunias (1990)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>Application Rate (Mg ha(^{-1}))</th>
<th>CT</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Weight (g kg(^{-1}))</td>
<td></td>
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<tr>
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<td></td>
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<td>6105</td>
<td>5093</td>
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<td></td>
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<td>5334</td>
<td>5197</td>
<td>5658</td>
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C.V. % = 13.6  L.S.D.(0.05) = 1030
Table 2. N Concentrations in Lettuce Leaves (Second Cut, 1991)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>Application Rate (Mg ha⁻¹)</th>
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<th>30</th>
<th>40</th>
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<tbody>
<tr>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>26.5</td>
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<td></td>
</tr>
<tr>
<td>*MEAN</td>
<td>25.7c</td>
<td>29.5</td>
<td>29.3</td>
<td>32.3</td>
<td>30.3</td>
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C.V. % = 14.6  L.S.D. (0.05) = 7.12
*Means do not include 40 Mg ha⁻¹ rate.

The fact that DSS provided more available N than DISS suggests that irradiation used to eliminate pathogen in sludge may have changed the N availability.

Except for a few exceptions, which could be explained, for DICSS and CLM, the N availability was equal to the content of inorganic N (NH₄⁺ -N + NO₃⁻ -N) + 10% of organic N. For sludge DISS, basically as same as composts, but in some cases, seemed a little higher percentage of organic N was available in comparison with composts application and CT (Table 3 & Table 4).

Table 3. N Concentration in Lettuce Leaves (First Cut, 1991)

<table>
<thead>
<tr>
<th>Organic Source</th>
<th>Application Rate (Mg ha⁻¹)</th>
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C.V. % = 6.5  L.S.D. (0.05) = 4.44
*Means do not include 40 Mg ha⁻¹ rate.
Table 4. N Concentration in Petunias (1990)

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C.V.% = 7.2  L.S.D. (0.05) = 3.94

In practice, this experiment has shown a way to use organic wastes as substitutes of chemical N to obtain satisfactory yields and to avoid unfavourable reduced yield sometimes happened with organic waste application.

Fig. 1. N Application in 1990

Fig. 2. N Application in 1991
THE EFFECT OF WAX AND POLYETHYLENE COATINGS ON THE DECOMPOSITION OF WASTE PAPER FROM QUICK SERVICE RESTAURANTS.

J.P. Winter and R.P. Voroney

This is a summary of our ongoing research into the bio-degradability of paper coated with wax, or polyethylene. An experiment was conducted into composting lobby and kitchen waste from a quick service restaurant. The lobby waste comprised paper packaging, and food discarded by customers. The kitchen waste contained rejected hamburgers, meat wrapping paper, and bread buns. Three composting treatments were set up as small piles (2-3 m³): 1) kitchen waste alone, 2) kitchen waste plus lobby waste, and 3) lobby waste with chicken manure. The degradability of naked, waxed, and polyethylene coated papers was tested by enclosing 3 cm² squares of paper in nylon mesh bags, and inserting the bags into the compost piles. Decomposition of the paper squares was observed by measuring their loss in mass over time.

The restaurant wastest composted slowly because of their high cellulose content. Adding poultry manure accelerated decomposition by providing micro-organisms with a better physical environment, and a source of readily available nitrogen, organic carbon, and other nutrients used for microbial growth. After 84 days of composting, the amount of original dry weight remaining was 51% for kitchen waste, 33% for kitchen plus lobby waste, and 29% for lobby waste plus manure. There was no significant difference (p < 0.05) in the rate of decomposition of naked or waxed paper squares, however, polyethylene coated paper decomposed at a rate 3 times slower.

Elemental analysis was conducted on the 84 day old composts, after fracturing clumps and passing through a 2 cm² screen. The composts without manure contained 50, 56, 20, 8, <2.5, <0.3, 16 mg/Kg of Mn, Zn, Cu, Ni, Cr, Cd, Pb, respectively. The concentrations of these elements were well within the safety guidelines for composts as set by the Ontario Ministry for the Environment. The composts without manure also contained 41% C, and 22% ash.

It was concluded that quick service restaurant wastes containing waxed paper can be composted. A polyethylene coating can retard decomposition in 3 cm³ pieces of paper. If polyethylene coated paper is included in the wastes, then fine chopping should be investigated as a means of enhancing its decomposition.

Further research is being conducted into the decomposition of the coated papers in soil.

REDUCTION OF NITROGEN LOSSES FROM ANIMAL MANURES BY STABILIZATION WITH AMMONIUM ADSORBING MINERALS

P. van Straaten, D.L. Burton, and P. Voroney

Ammonia losses from animal manures has an adverse effect on the air quality of livestock enclosures and reduces the nutrient value of the manure. The application of animal manure containing large quantities of ammonium increases the potential for rapid nitrate production and the contamination of surface- and ground- waters. The rate of ammonium release from adsorbing minerals and peat, when added to the soil, requires important consideration when assessing the efficiency of nitrogen use by the crop and the potential for using ammonium adsorbing materials for nitrate nitrogen (NO₃⁻) contamination of groundwater.

During the first phase of this Ontario Ministry of the Environment, funded project the potential of the appropriate adsorbing materials was evaluated. Only materials considered to be suitable for land application were tested. Naturally occurring geological resources (zeolites, bentonites, and vermiculites) were tested alongside two peats from N. Ontario. These materials were selected on the basis of their high adsorption and cation exchange characteristics and their practicality (cost/supply). The chemistry, mineralogy and ammonium exchange characteristics were determined to assess their suitability. The materials with the highest cation exchange capacity (174 - 190 cmol-
The soils were periodically leached over a period of seventy days following addition. The N release from the adsorbents was determined by measuring the mineral N (NH₄⁺ and NO₃⁻) concentration and ¹⁵N abundance of the leachates.

The NH₄⁺ retention of the adsorbents was related to their cation exchange capacities. Exposure to 325 mm (NH₄)₂SO₄ for 48 hours resulted in NH₄⁺ replacing from 27 to 62% of the total cation exchange capacity. The mass of adsorbent added to the soil was corrected to reflect the differences in C.E.C. There was no significant difference in the amount of adsorbed NH₄⁺ added to the soil.

The release of N, measured as total mineral N leached from the soil microlysimeters, followed first order kinetics with half-lives ranging from 52 to 128 days (fig. 1). The rate of N release from the adsorbents slowed the rate of N leaching from the microlysimeters. The N release rate of all adsorbents were suitable to release the majority of N retained to the crop in the year of application.

Figure 1 Nitrogen desorption from ammonium charged adsorbents added to a Conestogo silt loam and a Fox loamy sand.
ETHIOPIAN ROCK MULCH PROJECT TURNS TO PUMICE

P. van Straaten, W. Chesworth and P. Groenevelt

The Ethiopia-Canada project supported by the International Development Research Centre (IDRC) went into its final year of funding. Field work continued in the Nazaret-Melkassa area and at Zway in the semi-arid Rift valley where precipitation is unpredictable, and soil moisture stress is common and yield limiting. Rock mulching techniques were introduced in this area to increase water infiltration, to reduce run-off and to reduce evaporative losses. Volcanic scoria and pumice materials used in these field experiments come from huge local deposits. Grain size and layer thickness of the rock mulch turned out to be the most important variables in this technique. The results demonstrated that considerable reduction in evaporation could be achieved by rock mulching techniques on plots covered with 3 cm scoria and pumice layers with grain sizes of the rocks between 0.5 - 1.0 cm (see LRS report 1992).

This year's research focused on temperature measurements in soil profiles under plots covered with blackish scoria and whitish pumice, and uncovered plots. Results of this initial temperature survey show that soil temperatures under mulched plots are lower and less fluctuating than under unmulched plots. Temperature differences as much as 4°C were observed between mulched and unmulched plots at a 5 cm depth. Temperatures under plots covered with black scoriaceous rocks were usually 1-2°C higher than under plots mulched with whitish pumice.

Table 1. Soil temperatures in Ethiopian soil, Zway area, measured 27.3. 92.

a) surface temperatures (in °C)

<table>
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<tr>
<th></th>
<th>7.00h</th>
<th>11.00h</th>
<th>13.30h</th>
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<td>unmulched</td>
<td>22</td>
<td>35</td>
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<tr>
<td>mulched with 3 cm pumice</td>
<td>23.5</td>
<td>29.5</td>
<td>34</td>
<td>29</td>
</tr>
</tbody>
</table>

b) temperatures at 5 cm depth (in °C)

<table>
<thead>
<tr>
<th></th>
<th>7.00h</th>
<th>11.00h</th>
<th>13.30h</th>
<th>18.00h</th>
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<tbody>
<tr>
<td>unmulched</td>
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<td>29</td>
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<td>mulched with 3 cm pumice</td>
<td>25</td>
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<td>32</td>
<td>30</td>
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</tbody>
</table>

The main factors for higher yields under rock mulched fields in the semi-arid areas of the Ethiopian rift valley appear to be conservation of soil moisture and better and less fluctuating soil temperature regimes. During the 1992 season an innovative mulching technique was introduced in the Zway area. The new technique is making use of the low bulk density of the locally available cellular glassy lava, pumice. Pumice floats on water.

Pumice was applied in local papaya plantations and in bean fields. The irrigation technique commonly used in the local papaya plantations is to dig small basins around the papaya trees and, during the dry season, fill them every second day with water. The new technique involves filling the basins with a layer of locally available pumice. Upon irrigation the pumice tends to float and covers the surface of the water filled basin and reduces evaporative losses. After the water infiltrated into the ground the pumice covers the basin and has the effect of a ground mulch. The initial results of this technique are very encouraging as the frequency of irrigation could be reduced by about a half. Field tests continue to quantify the effectiveness of this new water saving technique.

A similar furrow mulching technique using pumice in bean fields was started on the Zway Horticultural Research Station and is currently being evaluated. The principle of this technique is illustrated in Figure 1.
NEW AGROGEOLOGY PROJECT IN ZIMBABWE

P. van Straaten and W. Chesworth

A new agrogeology project started at the end of 1992 linking the Department of Land Resource Science with the Institute of Mining Research and the Ministry of Agriculture in Zimbabwe. Like previous agrogeology research projects it is supported by the International Development Research Centre (IDRC), Ottawa. The project is based on work previously carried out by LRS personnel in Tanzania and Guelph and at the International Fertilizer Development Centre, USA.

The project's goal is to develop a low cost phosphate fertilizer using locally available resources from the phosphate mine of Dorowa. The phosphate minerals found at this mine are relatively insoluble fluorapatites which require processing and modification in order to become more soluble and hence more agronomically effective. Various methods of increasing the solubility of phosphates have been tested elsewhere over the last few years: partial acidulation, ion exchange (e.g. with zeolites), fusion, phospho-composting, biotreatment, biological modification, heap leaching and blending with acidifying minerals or fertilizers.

The project will make use of the already existing phosphate mine of Dorowa, some 300 km East of Harare, close to the farming area with acid, phosphorus deficient soils. The Dorowa phosphate plant extracts phosphatic ore (average grade: 6.5% P₂O₅) from a carbonatite complex. A problem associated with the processing and recovery of apatites from Dorowa mine is the loss of large amounts of phosphatic fines. Currently, approximately 200 000 - 300 000 tonnes of fines averaging > 4% P₂O₅ are discarded every year.

The modification technique which will be tested in Zimbabwe is that of blending and compacting Dorowa apatites with locally produced acidifying soluble fertilizers. This technique is proposed because of theoretical and practical considerations. The theoretical considerations are based on phase equilibria studies of the apatite/TSP mixture (see 1991 annual report of LRS, p. 44) which indicate that the apatite/TSP blend is a self-acidulating system, whereby phosphoric acid is being derived from the TSP or SSP granule by hydrolysis of TSP (mostly monocalciumphosphate/MCP). It is well known that a TSP granule (made up mainly of mono calcium phosphate)
attracts water from the soil and the H$_3$PO$_4$-laden solution with a pH of between 1 and 2 moves outward from the granule where it dissolves close by mineral substances. The pH of this solution is sufficiently low to dissolve over time the relatively insoluble apatite if it is in close spatial contact.

It is anticipated that the compacted blend reacts in the soil with water and an in-situ acidulation process of the apatite minerals is being induced by the hydrolysis of TSP in the soil. Preliminary laboratory results at LRS indicate that the phosphoric acid produced by hydrolysis of TSP will induce partial acidulation of the apatites which is compacted together with the TSP. A close contact of TSP granule and apatite is essential as it will facilitate increased effectiveness of this in-situ acidulation process.

The proposed blending and compacting techniques using an acidulating, quick soluble starter fertilizer (e.g. TSP) and the less reactive Dorowa phosphate will have not only agronomic and economic advantages but also some practical benefits: processes using concentrated acids are not required, and, preparing a complex P- fertilizer by mixing two originally dry products is easier than reacting phosphates with acids and curing them. Also, the handling problems associated with the recovered apatite fines will be substantially reduced by the compaction technique.

The blended local phosphate fertilizers are designed for communal farmers of Eastern Zimbabwe who farm on marginal lands, in overpopulated communal lands and in areas of intense resettlement. Here, soil fertilities are low, specifically the ortho-ferralitic sandy soils developed on granites. These soils are commonly very acidic and phosphorus deficient and require nutrient additions to maintain or increase soil productivity.

Positive results of this research will be of wider application in Central and East Africa and has considerable potential for application also in less acid soils. The project's aim of increasing the recovery of phosphate fines from the Dorowa phosphate deposit and process and modify these apatites of low solubility into agronomically more effective products is part of an overall strategy to find technical solutions to make better use of Eastern and Southern Africa's igneous phosphate resources.
Land
Inventory & Stewardship
EVALUATION OF AGRICULTURAL LAND TRUSTS

S. Hilts and P. Mitchell

Over the past two years, a focused collaborative research program has been developed to evaluate the usefulness of Land Trusts as community organizations to promote conservation. This program includes examining the use of Land Trusts to protect natural environments in general, and to protect agricultural land. During the project it has also become apparent that Land Trust activity is also often tied to providing residential accommodation, or affordable housing.

The highlight of this program was an extremely successful workshop on Land Trusts in Ontario, held on Mar. 31, 1992. It was attended by 200 interested delegates, and was so popular that another 30 interested individuals had to be turned away. The day featured presentations by representatives of several organizations in Ontario, and served to make many different groups aware of related work by others. It also focused attention on key research and organizational questions which have been the focus of attention since.

During the following 8 months, follow-up research has been conducted in three main areas. First, several meetings have been held with lawyers to explore legal questions. Secondly, five U.S. Land Trust organizations were visited, to obtain a clearer under standing of some of the organizational limits of Land Trusts. Finally, a research paper has been compiled specifically on Agricultural Land Trusts.

In addition to this ongoing research, a handbook entitled Creative Conservation: A Handbook for Land Trusts in Ontario is nearing a final draft. During the past year, approximately 150 requests for information on Land Trusts were handled, and a major funding proposal was developed and submitted to enable further collaborative research on a more intensive scale. Discussions have also been held with a view to establishing a University-based Land Trust.

DEVELOPMENT OF CONSERVATION PLANNING HANDBOOK

S. Hilts and P. Mitchell

Over the past ten years, research on approaches to encouraging private stewardship of land resources has developed under the 'Natural Heritage Stewardship Program'. Numerous publications can be found in past Annual Reports related to this. A major need identified during the latter years of this program was the need for a simple, written agreement that landowners could enter into as evidence of their commitment to stewardship.

The developing 'Environmental Farm Agenda' in Ontario will provide a framework for such a step by farm landowners, but no-farm landowners tend to be left out. During 1992 a major effort has therefore been placed on the development of a Conservation Planning Handbook for rural non-farm landowners. This Handbook will lead the interested landowner through a series of steps to develop a stewardship plan for their land. Initial field development of this process was completed during 1992, with the co-operation of six landowners in Grey County as partners.

A draft of this Handbook will be available in the spring of 1993, and further development will be undertaken over the coming year.
CENTRE FOR LAND AND WATER STEWARDSHIP

S. Hilts - Director

At the beginning of 1992, the Centre for Soil and Water Conservation, initially sponsored by the Department of Land Resource Science, was renamed the Centre for Land and Water Stewardship. With a mandate to expand the activity of the Centre, Dr. Stewart Hilts took over from the first Director of the Centre, Dr. Murray Miller, as of January 1st, 1993.

The foundation of the Centre consists of two cornerstone programs:
- the Chair in Land Stewardship, held by Prof. Michael Goss, and the Soil and Water Conservation Information Bureau.

Prof. Mike Goss was appointed to the Chair in Land Stewardship in August, 1990, and has developed major research initiatives related to the impact of agriculture on the environment. He is investigating the use of nitrogen budgets for a whole farm to predict groundwater contamination with nitrate. The working committee of Ontario Farm Groundwater Quality Survey was Chaired by Mike representing the Centre for Land and Water Stewardship.

The Soil and Water Conservation Information Bureau was established in 1989 as an element of the SWEEP Program, with a mandate to promote soil and water conservation through providing up-to-date information for innovative farmers. Their work has involved intensive networking with farmers over issues such as conservation tillage.

Through the Newsletter Infosource, this information is shared with approximately 10,000 interested farm owners.

A major initiative of the Information Bureau has been to provide the secretariat for the Innovative Farmer’s Conference. During 1992 the fifth such conference was held in London. It was an overwhelming success, with attendance of over 400 stretching the facilities to the limit.

The life of the Information Bureau under the SWEEP Program officially ends in early 1993. At press time, we have just heard that its work will be renewed for at least four years, through Green Plan funding from Agriculture Canada.

For further information contact:

Prof. Michael Goss, Chair, Land Stewardship.
Mr. Doug Robinson, Manager, Soil & Water Conservation Information Bureau.
Prof. Stewart Hilts, Director, Centre for Land and Water Stewardship.
Publications
Papers Presented
Seminars
TITLES OF BOOKS AND CHAPTERS IN BOOKS


PUBLICATIONS IN REFEREED JOURNALS


NON-REFEREED REPORTS AND PUBLICATIONS


SEMINARS AND PAPERS PRESENTED


Kay, B.D. and V. Rasiah. 1992. Quantifying the rates of change in clay stabilization subsequent to introduction of forages. ASA Annual Meeting, November 1-6, Minneapolis.


DEPARTMENTAL SEMINARS


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M = DATA MISSING

"Dif." equals this year’s value minus the 1951 - 1980 normal value.