1991
ANNUAL REPORT
LAND
RESOURCE
SCIENCE
UNIVERSITY
OF GUELPH
Best wishes were extended by Bev Kay on behalf of the Department of Land Resource Science to Marg and Tom Bates on Tom's retirement after 30 years of service.

Congratulations is extended to the Morwick Scholarship recipient John Paul by Douglas Tate, gradson of Barbara Morwick Tate (grad Mac '56) and acting chair Dr. Eric Beauchamp.
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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.

Many of these developments arise from increased emphasis being placed on enhancing society’s capability to use our rural resources in a more sustainable manner.

The process of restructuring our undergraduate programs has been completed. A new major in Agronomy was introduced in the B.Sc. (Agr.) last year and replaced the former Soil Science and Crop Science majors. This major is offered jointly by Land Resource Science and Crop Science. A new major in Earth and Atmosphere Science has been approved for inclusion in the B.Sc. (Env.) program. The new major will replace the existing Earth Science and Environmental Soil Science majors. The restructuring of our undergraduate programs will enhance the ability of our students to deal with issues related to production agriculture and the management of the biophysical environment.

The Department is in the process of combining and restructuring our two graduate programs, Agrometeorology and Soil Science, into a single graduate program. The new program will recognize the evolution of areas of specialization within the graduate faculty over recent years and the current international trend to develop research programs with increased collaboration among the disciplines concerned with terrestrial ecosystems. The new program will focus on understanding better the atmospheric, soil, and geological components of our physical environment as well as the interactions between them and with water resources and plant communities. The program also will emphasize research on the use and management of land resources for agriculture, waste management, forestry, and other activities.

Research programs have continued to grow with the greatest growth in studies related to diminishing soil degradation and improving 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. A highlight in extension has been the Partners in Nitrogen project 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.

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 M. Metcalf, D. Irvine and S. Mott in assembling this report and in encouraging all of us to meet publication deadlines.

B.D. Kay
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. (Ag.), M.Sc. (McGill), Ph.D. (Cornell), Professor and Acting Chair. Nitrogen in the soil/crop system; manures; fertilizers and plant nutrition. (Ext. 3239).

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

D.M. BROWN, B.S.A., M.S.A. (Toronto), Ph.D. (Iowa State), Professor. Climate related to land use planning, crop zonation and irrigation feasibility. (Ext. 2206).


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), Associate 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), Co-ordinator of O.I.P. Computer Laboratory and Teaching Associate. Soils science, resources planning and management. (Ext. 3393).

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).


S.G. HILTS, B.A. (Western Ontario), M.A. (Toronto), Ph.D. (Toronto), Associate Professor. Joint appointment with University School of Rural Planning and Development. Natural resources management, environmental planning, land utilization. (Ext. 2702).

R.G. KACHANOSKI, B.Sc., M.Sc. (Saskatchewan), Ph.D. (California, Davis), Assistant 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 Assistant. Electronic instrument development; transport processes within and above plant canopies. (Ext. 2434).

K.M. KING, B.S.A. (Toronto), M.S., Ph.D. (Wisconsin), Professor. Agronomic prototypes: evapotranspiration and photosynthesis of field crops and forests; effects of elevated atmospheric CO2. (Ext. 2787).


J.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), Assistant Professor. Soil science and agricultural land use planning. (Ext. 2492).

T.P. MCGONIGLE, B.Sc. (Sussex), D.Phil. (York), Research Associate. Vesicular-arbuscular mycorrhiza and their effect on plant growth. (Ext. 8748).

M.H. MILLER, B.S.A. (Toronto), M.S., Ph.D. (Purdue), Professor. Soil fertility, plant nutrition and soil and water conservation. Director, Centre for Soil and Water Conservation. (Ext. 2462).


E. PERFECT, B.Sc. (Newcastle-upon-Tyne), M.A. (Carleton), Ph.D. (Cornell), Research Associate. 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. (Sidhu), Scientist. Land stewardship cropping systems. (Ext. 3393/8166).
Clerical/Technical Staff


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

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

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

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


M. EIKELBOOM, Dipl. Hort. (Guelph), Research Assistant. Land Stewardship. (Ext. 4266).


E.F. GAGNON, Assoc. Dipl. Agr. (Guelph), Supervisor. Analytical Services Laboratory. (Ext. 2494).


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


M.J. METCALF, Secretary. (Ext. 6365).


D. MOTAYNE, Clerk. Filling in for Maternity Leave, May-November.


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. 2465/2661).

K. SHEFLET, B.Sc. (Carleton), Research Assistant. Agriculture Canada Research Station, Delhi.

P. SMITH, B.A. (Guelph), Technician. Land Stewardship. (Ext. 4265).


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


*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.
The New Undergraduate Environmental Sciences Program

S. Hilts

Over the 1990 and 1991 years, the Department of Land Resource Science had a major input to the new undergraduate Environmental Sciences program, the B.Sc.(Env.). We are the only department which put forth two undergraduate majors for inclusion in this new degree, and Stewart Hilts of our faculty served as the Coordinator for the Committee that prepared the entire new proposal.

Under the new degree, the former Environmental Soil Science and the Earth Science majors, in the B.Sc. program, were combined to form the new Earth and Atmosphere Science Major in the B.Sc.(Env.). The former Resources Management Major was renamed the Natural Resources Management Major, and made available in both the B.Sc.(Agr.) degree, where it has always been, and in the new B.Sc.(Env.).

This restructuring is an innovative step forward in trying to adapt our undergraduate programs to address society’s pressing need for scientific solutions for environmental issues. Developing and promoting the new majors will be a major challenge for the department in the coming years.
# Undergraduate Education

**Undergraduate Diploma and Degree Courses Offered During 1991.**

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<th>Course No.</th>
<th>Course Name</th>
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<td>Land Resources and Environmental Quality</td>
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<td>Managing Soils for Crop Production</td>
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<td>Problem Solving in Land Resource Science</td>
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<td>87-407</td>
<td>Problems in Land Resource Science</td>
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<td>Soil Plant Relationships</td>
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<td>87-420</td>
<td>Issues in Land Resources</td>
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### Graduates in Soil Science, Resources Management and Earth Science
Spring, Fall 1991, and Winter 1992

<table>
<thead>
<tr>
<th>SOIL SCIENCE MAJORS</th>
<th>RESOURCES MANAGEMENT MAJORS</th>
<th>EARTH SCIENCE MAJORS</th>
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<tbody>
<tr>
<td>Mathew Aerts</td>
<td>Allan Alderson, Doug Bodo, Stephen Burtt, Patricia Brunt, John DeGagne, Donald Depuydt, Peter Ferguson, Ron Fournier, Paul Hallett, Paul Hermans, Katherine Howe, Shirley MacDuff, Esther McKnight, Brenda Newman, Jeff Obbema, Brent Robinson, Mohammad Shams, Mary Skinner, Shawn Strangways, Anne Sweet, Patrick Wrozek</td>
<td>Bruce Blackburn, Brian Smith, Cynthia Styles</td>
</tr>
</tbody>
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### Undergraduate In-Course Awards
November 1991

- **John A. Archibald Memorial Scholarship**
  - Stephen Fraser
  - Environmental Soil Science

- **Robert McCann Scholarship**
  - Lynn Rowan
  - Resources Management

- **Robert Harcourt Scholarships**
  - Stephen Litke
  - Resources Management

- **Kae & Gordon Skinner Memorial Scholarship**
  - Mathew Aerts
  - Soil Science

- **N.R. Richards Scholarship**
  - Christopher Duke
  - Resources Management

- **J. Ross Cavers International Scholarship**
  - David Jones
  - Resources Management

- **Foodland Hydro Scholarship**
  - Jeremy Higham
  - Resources Management

- **The G. Elmore Reaman Family Award**
  - Lynn Rowan
  - Resources Management
Dean’s Honours Recipients

W’91
Peter Chesney
Peter Ferguson
Jackie Fraser
Stephen Fraser
Jon Gingerich
David Jones
Bubby Kettlewell
Tracey Lawrence
Stephen Litke
Brian Odell
Adriana Perkins
Peter Presant
Lynn Rowan
Mary Skinner
Patricia Story
Anne Sweet
Debra Tallan
William Whiting

Soil Science
Resources Management
Resources Management
Environmental Soil Science
Resources Management
Resources Management
Resources Management
Earth Science
Resources Management
Earth Science
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management

F’91
Sara Barber
Linda Cain
Peter Chesney
Ronald Fournier
Jackie Fraser
Stephen Fraser
Jon Gingerich
Paul Hallett
Jeremy Higham
Pamela Joosse
Bubby Kettlewell
Hannah King
Tracey Lawrence
David Lisko
Tara McCaughey
Sheila Murphy
Ramadhan Ngatoluwu
Brian Odell
Adriana Perkins
Lynn Rowan
Mary Skinner
Stephen Stenabaugh
Debra Tallan
Angela Tallan
William Whiting
Bronwynne Wilton

Resources Management
Resources Management
Soil Science
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Earth Science
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
Resources Management
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Resources Management
Resources Management
Resources Management
Resources Management
Graduate Education

The Department of Land Resource Science offers a wide range of opportunities for graduate studies at the M.Sc. and Ph.D. levels. M.Sc. programs are available in Agrometeorology, Soil Science, and in Resources Development (in conjunction with the University School of Rural Planning and Development). An M.Agr. program is offered in Land Management and Agricultural Land Use. Ph.D. programs are available in Agrometeorology and Soil Science. The Department also participates in the interdepartmental groups on Biophysics, Hydrology, Plant Physiology, and Toxicology whereby a student registered in the Department, may enrol and specialize in one of those disciplines.

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 analysers, 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 - K.M. King
Soil Science - R.L. Thomas

Graduate Students and Advisors - Winter Semester, 1992
SOIL SCIENCE PROGRAM

M.Sc. Students
Anderson, Mitchell
Covert, Jeff
Dey, Anton
Eshraghi, Navid
Fallow, David
Gibson, Rick
Goorahoo, David
Husain, Jaihali
King, Don
Loro, Petra
Lortie, Luc
MacDonald, Sara
MacKay, Wally
Makalew, Anna Maria
Milne, Deborah
O'Brien, Gavin
Oluku, Hillary
Pringle, Elizabeth
Rombang, Johan
Siregar, Adelina
Tenuta, Mario
Vandenbygaart, Bert
Vanderwel, Paul
Veenhof, Derek
Wanniarachchi, Sudas
Young, Michael

Advisors
P.H. Groenevelt
E.G. Beauchamp
E.G. Beauchamp
B.D. Kay
D.E. Elrick
R.G. Kachanoski
M. Goss
P.H. Groenevelt
C.J. Wall
E.G. Beauchamp
R.L. Thomas
E.G. Beauchamp
D.E. Elrick
P.H. Groenevelt
W. Chesworth
D.E. Elrick
L.J. Evans
R.G. Kachanoski
P.H. Groenevelt
R.P. Voroney
E.G. Beauchamp
R. Prozt
T.E. Bates
R.A. McBride
R.P. Voroney
R.G. Kachanoski

Ph.D. Students
Addy, Heather
Bergstrom, David
Beyaert, Ron
Bolton, Kim
Dagesse, Daryl
da Silva, Alvaro
Denholm, Ken
Hamlen, Catherine
Hou, Junning
Lobb, David
Lu, Shen
McCabe, Don
McCarthy, Paul
Parkin, Gary
Sheep, Gene
Sweeney, Stewart
Ward, Anderson
Wen, Guang
Winter, Julien
Zhang, Zhiyuan

Advisors
M.H. Miller
E.G. Beauchamp
R.P. Voroney
L.J. Evans
B.D. Kay
B.D. Kay
B.D. Kay
R.G. Kachanoski
L.J. Evans
R.G. Kachanoski
M.H. Miller
R. Prozt
I.P. Martini
D.E. Elrick
W. Chesworth
R. Prozt
R.G. Kachanoski
R.P. Voroney
R.P. Voroney
R.P. Voroney
Graduate Students and Advisors - Winter Semester, 1992
AGROMETEOROLOGY

M.Sc. Students
Lin, Mei
Lyanuchai, Charles
Popa, Romeo
Simpson, Isobel
Wang, Xiaolong

Advisors
G.W. Thurtell
T.J. Gillespie
Thurtell/King
G.W. Thurtell
T.J. Gillespie

Ph.D. Students
Edwards, Grant
Fuentes, Jose
Cordon, Robert
Groot, Arthur
Riddle, Claudia

Advisors
G.W. Thurtell
T.J. Gillespie
D.M. Brown
K.M. King
T.J. Gillespie

---

Graduate Degrees Conferred Spring, Fall 1991 and Winter 1992

<table>
<thead>
<tr>
<th>Student</th>
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**Agrometeorology**


Barr, Alan Ph.D. T.J. Gillespie Local and Regional Estimates of Sensible and Latent Heat Flux Densities from Patch-Work Surface Nov. 7, 1991

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**GRADUATE AWARDS NOVEMBER 1991**

**Soden Fellowships in Agriculture**
- David Fallow
- Isobel Simpson
- Paul Van der Werf

**Mary Edmunds Williams Fellowship**
- Heather Addy
- Gary Parkin

**Commonwealth Scholarship**
- Aston Chipanshi
- Mathias Fosu
- Sudas Wanniarchichi

**University of Guelph Graduate Fellowship (Department)**
- Junning Hou
- Derek Veenhof
- Sudas Wanniarchichi

**University of Guelph Graduate Fellowship (Open)**
- David Bergstrom
- David Fallow
- David Goorahoo
- Cathy Hamlen
- Paul McCarthy
- Gary Parkin

**Ontario Graduate Scholarship**
- Don McCabe

**IDRC Scholarship**
- Anton Dey
- Edwin Mchihiyo

**Ontario Differential Tuition Waiver Award**
- Zhiyuan Zhang (S'91)
- Xiaolong Wang (S'91, F'91)

**Monsanto Turf Grass Research Fellowship**
- Paul van der Werf

**Visa Scholarship**
- Cheng Yong Zhang (W'91)
- Zhiyuan Zhang (F'91)
- Mei Lin (F'91)

**CIDA Scholarship**
- Jailani Husain
- Charles Lyamchui
- Hillary Oluo
- Johan Rambang

**Netherland Government Scholarship**
- Paul van der Werf

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**World University Service of Canada**
- Anna Maria Makalew

**Morwick Scholarship**
- John Paul
Extension Highlights

D. Murray Brown

The Outreach and Extension activities in Land Resource Science during 1991 included significant time supporting provincial programs on nitrogen and waste applications on agricultural land, a nitrogen soil test, composting and the wind-up of the Tillage-2000 and SWEEP programs. Other activities on committees, workshops, field days and participation at county OSCIA meetings and seed/field days continued at the usual level. A special meeting was held to discuss research activities in LRS and how they should ‘dove-tail’ with research and extension efforts of the OMAF Resources Management Branch. Outreach to individuals, businesses, government agencies and the media through telephone and office visits continued at the usual level.

The extension/research program called Partners in Nitrogen, initiated in 1990, was established successfully in most counties on pilot farms through local management teams made up of local fertilizer dealers (TFIO members) and soil and crop advisors. There were farm sites in this program in 1991. A soil test for nitrogen, that was proposed from this program in 1990, was carried out on farm soil samples in the spring of 1991. Further evaluation of this testing procedure continues. Another outgrowth from this program was a project initiated this year to test ground water for contamination by nitrogen and other chemicals. There were 1350 water samples analyzed from wells in this federal/provincial project being conducted cooperative-ly between the University of Guelph Centre for Land and Water Stewardship, the University of Waterloo Centre for Groundwater Res-earch, the Ontario Soil and Crop Improvement Association, the Ministry of Agriculture and Food and Agriculture Canada.

Considerable effort was devoted to advising government Ministries and other organizations on procedures for application of manure, sewage sludge and other wastes on land, large-scale composting operations, and waste reduction activities. Per-
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 1991 was approximately $3.4 million. This amount represents a further significant increase over last year. The Ontario Ministry of Agriculture and Food contributed $1.29 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 Ministry of Natural Resources
- Ontario Heritage Foundation
- Ontario Ministry of Agriculture and Food (special projects)
- Environment Canada
- Ciba-Geigy Canada Ltd.
- The Fertilizer Institute of Ontario, Inc.
- Indian Affairs and Northern Development Canada
- 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.
- IGI International Wastes
- Imperial Oil Ltd.
- North Atlantic Treaty Org.
- Energy, Mines and Resources Canada
- Phiom Bias
- Supply and Services Canada
- Inco Ltd.
- Ontario Ministry of Northern Development and Mines
- Dofasco Inc.
- Environmental Soil Services Ltd.
- Wildlife Habitat Canada

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 1991 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
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Land Characterization
Applications of Geographic Information Systems (GIS) for Soil Survey Upgrading In Ontario

C. FitzGibbon and J. Lombard

The currently existing soil data base for Ontario varies significantly in its accuracy, reliability and conformity to established standards. Existing maps are either on a county or regional basis and are at varying scales. This variation exists because of changes that have been made to soil survey methods, sampling and data collection and classification procedures. The existing soil information in many cases is extremely general. Sometimes only soil classes are identified, with little or no topographic information and only very general definitions of texture and drainage classes. Specific data indicating slope, texture and drainage information is extremely important for determination of soil capabilities for agricultural production and land use planning, and for calculation of potential soil erosion, making it vital for use in soil conservation programs. The soil data base for Ontario needs to be upgraded to include this vital information and to bring the data base to a consistent level of accuracy and reliability.

This study examined the potential for using digital data and GIS technology to assist with upgrading older soil survey information in Ontario in a rapid and cost effective fashion. The Terrasoft GIS system has good capability for analysis and modelling of the topography of an area. The topography can be represented by a Digital Terrain Model consisting of a number of points, each with values for X (northing), Y (easting) and Z (elevation).

A small study area located in the Northern portion of Oxford County was chosen as a test site. The site is approximately 4500 hectares in area, surrounding the town of Plattsville in Blandford-Blenheim Townships.

The existing soil information for the study area, which consisted of soil polygons and the soil series information, was extracted from the ARC/INFO soil data base at the Ontario Centre for Soil Resources Evaluation and transferred into the Terrasoft system. Topographic information was added to the data base by digitizing contours from the 1:25,000 topographic map with a contour interval of 3 m (10 ft). The contour information was used to generate DTM for the study area and slope angles then calculated for grid cells 0.25 hectares in area. The resultant map was classified into slope categories similar to the standard slope classes used for the Ontario soil survey.

When the resultant slope map was compared to slopes as estimated by a soil surveyor, it was found that the model slope estimate agreed with the surveyor estimate 63% of the time. Another 32% of the predicted slopes missed the surveyor estimate by only one slope category.

The Terrasoft GIS has good potential for use in soil survey to map topographic slope from existing contour information. Further work is underway to pursue the use of DTM’s in soil survey.

Using Satellite Imagery to Map Crop Residue Cover on Fields in the Lake Erie Watershed

Heather McNairn and Richard Protz

Introduction

Work has continued over the past year on the use of satellite imagery to map corn residue cover. Traditionally, information on conservation adoption has been compiled by conducting personal interviews and mail surveys, and by collecting on-site data. The windshield survey, which involves visually estimating the percent residue cover on a sample field, is the most commonly used procedure to collect on-site data regarding conservation tillage adoption. Percent crop residue cover can also be estimated using the knotted rope method. Remote sensing could, however, be a relatively inexpensive alternative for estimating residue cover.

The three main objectives of the study were as follows:

1. To investigate the correlation between residue and reflectance from bare/residue covered surfaces;
2. To develop a methodology to predict percent crop residue cover from spectral reflectance; and
3. To test the ability of the developed methodology to predict the correct percent residue category.

Methodology

Oxford County in southwestern Ontario was chosen as the research area. Seventy-nine corn residue fields were surveyed in April of 1990 prior to spring tillage. Within each field, residue measurements and soil samples were taken along a transect parallel to the field boundary. At each sample point, one residue measurement was made using the knotted rope method. A composite soil sample was taken at most sample points and samples were analyzed for particle size distribution, organic matter content and pH. Four to six residue measurements and three to four composite soil samples were...
Figure 1. Index values vs percent residue cover, sandy soils.

Figure 2. Index values vs percent residue cover, silly soils.

Figure 3. Index values vs percent residue cover, clayey soils.

Figure 4. Index values vs percent residue cover, all textures.
made on each field.

A seven band Thematic Mapper (TM) image for April 18, 1990, was acquired for the study area. Each sample point was located on the imagery. In each band, the spectral value of the pixel in which the measurement was located was extracted from the imagery. A simple linear model was then generated to define the relationship between reflectance and percent residue cover. Reflectance was represented as either single band values or Normalized Difference Index (NDI) values.

Initially, residue measurements were separated into three categories based upon the texture of the soil on which the measurements were made (silt loam, clay loam, and loamy sand/sandy loam). Soils were categorized according to their textural designations in the 1961 Soil Survey of Oxford County. To form the models, 75% of the data within each textural class was randomly selected. Based upon the results of the simple regression and the coefficients of determination, one model for each textural category was chosen and tested for its ability to predict percent residue cover. Prediction ability was tested on the remaining 25% of pixels. The observed residue percent (as measured using the knotted rope) was compared to the predicted percent (as generated by the regression model). Predictions were considered correct if the predicted percent residue cover fell into the same residue category as the measured percent residue cover. Multiple linear regression was then used to evaluate whether incorporating a second NDI in the model would improve the prediction accuracy of the model.

All of the data (over all textures) was used to form a multiple linear equation to model the relationship of reflectance with percent residue cover as well as soil parameters. The independent variables entered included the percent residue cover, percent sand, percent silt, percent clay and organic matter content. The NDI with the strongest relationship with percent residue cover, as indicated from the simple regression, was entered into the model as the dependent variable.

Results

Across all single bands, percent residue cover on silt textured soils is most highly correlated with reflectance. A much weaker, but still statistically significant relationship, exists between residue cover on sandy textured soils and reflectance in TM wavebands. In all textural categories, the relationship between reflectance and percent residue cover is positive.

Percent corn residue is significantly correlated with most NDI values. Indices involving Band 5 (middle infrared) and Bands 1, 2, 3 or 4 consistently have the highest correlation with percent residue. Except for silt textured soils, the near IR/middle IR (NIR/MIR) NDI [(Band 4-Band 5)/(Band 4+Band 5)] exhibits the strongest relationship with percent cover. For silt soils, the correlation between the NIR/MIR NDI and residue cover is only slightly lower than the correlation between the green/middle IR NDI and cover. Figures 1, 2, 3 and 4 plot the relationship between the NIR/MIR NDI values and percent corn residue cover. The lowest correlation between percent residue cover and the NIR/MIR NDI is for sandy soils; residue cover on silt soils has the highest correlation with index values.

Percent residue cover is more strongly correlated with the NIR/MIR NDI values than with single band values or any other index value. Consequently, the NIR/MIR NDI was further investigated for its ability to predict percent residue cover. Predicted (from the model) and measured (from the knotted rope) residue percentages were compared on a pixel by pixel basis. Residue measurements taken on sandy textured soils (n=103) could not be predicted with a high degree of accuracy using the NIR/MIR NDI. Overall, only 65% of these residue measurements were predicted into the correct category. When the index values are used to predict residue cover as simply less than or greater than 20% cover, 82% of residue measurements taken on sandy soils are correctly classified. For 92% of pixels on silt soils (n=78) and 86% of pixels on clayey soils (n=85), the index correctly classifies the amount of residue cover into one of three categories. A slight improvement in prediction accuracy was achieved for both textural categories by reducing the number of residue categories to two. For both silty and clayey surfaces percent residue cover on 96% of test pixels is correctly classified as less than or greater than 20%.

A model was also generated to predict residue cover from NIR/MIR NDI values across all soil textures. Sample sites were not separated by soil texture (n=266). Using this model, 78% of residue measurements are correctly predicted into the three residue categories. When only two prediction categories are used, 90% of residue measurements are correctly classified by the model.

The NIR/MIR NDI is able to predict the amount of residue on clayey and silty textured soils with a high level of accuracy. However, it would be beneficial if prediction accuracy improved, especially when residue is located on sandy textured surfaces. In order to maintain simplicity, only one additional NDI was added to the model.

For sandy soils, when either the (B4-B7)/(B4+B7) (near IR/far IR NDI) or the (B5-B7)/(B5+B7) (middle IR/far IR NDI) index is included in the model, percent residue for 79% of test pixels is correctly classified into three categories (an increase from 65%). Percent residue for 94% of test pixels is correctly classified into two categories (an increase from 82%). For silty and clayey textured soils, including a second ratio will not improve the prediction accuracy of the models. When pixels are not separated by soil texture, including a second NDI in the model results in a slight improvement in prediction accuracy. Models which included (B4-B7)/(B4+B7) or the (B5-B7)/(B5+B7) index as a second ratio have the highest prediction accuracy (92% of test pixels correctly classified).

When soil parameters and residue cover percentages were entered into the full model, simple multiple linear regression reduced the full model to the following:

\[ Y_i = -0.331583 + 0.001221X_{i1} + 0.000267X_{i2} + 0.000097X_{i3} + e_i \]
where \( Y \) = near infrared/middle infrared NDI
\( X_1 \) = percent residue
\( X_2 \) = percent silt
\( X_3 \) = percent clay
\( p < .001 \)
\( i = 1 \) to 318

Approximately 80% of the variation in the index values is explained by percent residue, percent silt and percent clay.

Percent organic matter is not included in the reduced model. This variable may not be included for several reasons. Research indicates that the relationship between reflectance and organic matter is significant only for soils with high organic matter content. All soils sampled in this study were mineral soils, 96% having less than 6% organic matter. Studies that have related soil parameters to reflectance have been carried out on bare soils (no surface vegetation cover). A significant relationship between organic matter content and reflectance may occur when residue cover is low.

One advantage of using NDI instead of single band digital numbers is that the index has the potential to remove or reduce the influence of background soil parameters. The small but significant increase (approximately 5%) in the coefficient of determination, which results when soil textural information is included in the model, indicates that these soil parameters do vary to some degree with index value with percent residue held constant. The regression coefficients, however, suggest that this relationship is weak.

To investigate the relationship between soil factors, particularly organic matter content and index values at low residue cover, data were separated into categories according to percent cover. Three categories were used: samples taken from surfaces with less than 30% residue cover, less than 20% cover and less than 10% cover. Each NDI was regressed on the soil and residue variables. Stepwise multiple regression reduced each full model.

Results suggest that, on surfaces with less than 30% cover, index values are sensitive to both residue and soil variables. However, at less than 20% cover, index values are often significantly related to only soil variables. These relationships suggest that predicting percent cover from index values when residue amounts are low, may be difficult. The relatively low coefficients of determination suggest that other variables, such as soil moisture or surface roughness, are contributing to the variation in index values.

The NIR/MIR NDI was then used to classify residue cover on the April 18, 1990 image of Oxford. All bare/residue covered surfaces were classified into three residue categories. Results of the classification indicate that in Oxford County, over half of corn residue surfaces have less than 20% cover. Twenty-nine percent of residue surfaces have between 21 and 45% cover and only 14% have more than 45% cover.

Summary

When predicting residue cover for a study area, it is recommended that surfaces be separated by soil texture according to existing soil surveys. A separate prediction model would then be applied to each soil texture category. High prediction accuracies can be expected for silty and clayey textured surfaces when the model includes only the NIR/MIR NDI. Inclusion in the prediction model of either the near IR/far IR or middle IR/far IR NDI as a second index is recommended for predicting residue cover on sandy textured soils.

The methodology developed is able to successfully classify residue cover using NIR/MIR NDI values. Monitoring conservation tillage adoption using this method would be inexpensive relative to on-site surveys. The method has also proven to be relatively easy to implement.

Future work will involve application of the developed classification methodology to other areas of southwestern Ontario. Work is also underway to include bean residue surfaces in the classification. The integration of the classified residue map with GIS vector files is also being carried out. GIS vector files of road networks, political boundaries and physical units are being encoded into the classified map.

Defining Appropriate Scales For Remote Sensing Data On Coastal Wetlands - An Example From James Bay, Ontario

Heather McNairn, Richard Protz and Chris Duke

Introduction

The fluctuations in sea level that result from global climatic change could significantly impact the ecology of coastal wetlands. Recent evidence of climatic change due to anthropogenic activity has increased the importance of developing methods to map coastal ecosystems in order that changes in these systems can be quickly detected and measured. The James Bay coast is dynamic and sea level changes would be readily detected. This study examines the impact of pixel resolution on the classification of northern wetland ecozones using remote sensing data.

Methodology

In July of 1990, MEIS-II imagery was collected for a section of the James Bay coastline. Spectral data were collected in 8 wavebands (6 visible and 2 infrared) at a 5 metre spatial resolution. At the time of imaging, landcover was noted and videotaped at 50 metre increments along a 1,000 metre transect orthogonal to the Bay. Summary statistics of the spectral data indicated a high correlation among the visible bands and between the infrared bands. These correlations suggest that
a substantial amount of redundancy in spectral information exists among bands. Consequently, one infrared band (0.751µm) and the green-red band (0.597µm) were used to perform a supervised classification on the image.

To simulate various scales, a pixel was selected near the centre of each landcover classification. A mean and standard deviation was calculated for the 5 metre spectral data within the successively larger pixels. If for two classes the mean digital numbers ± one standard deviation did not overlap in at least one band, the classes were considered spectrally separable. Simulated scales ranged in resolution from 10 metres (simulating SPOT panchromatic imagery) to 1,280 metres (simulating NOAA AVHRR imagery). The 5 metre MEIS-II imagery was then resampled to generate simulated images at various scales. An unsupervised classification was then carried out on each simulated image.

Results

A supervised classification generated 15 spectrally separable landcover categories. When pixel size increased to greater than 40 metres, the number of separable landcover categories decreased. At a 1,280 metre resolution, only 4 categories were separable. At coarser resolutions, the variability in spectral values within these broader classes generally increased as indicated by the increase in standard deviations. The unsupervised classification of the resampled images generated 16 land cover classes for each of the 20, 50, 40 and 80 metre pixel resolutions. However, even at a 1,280 metre resolution, 11 classes were produced from this classification. Although the unsupervised classification generated more land cover classes over the entire image, fewer classes were present on the coastal area.

Summary

Although airborne imagers are often used as aids to classify ecozones at large scales, the expansion of northern wetlands and results from this study suggest that the use of spaceborne imagers such as SPOT (20 metre MSS resolution) and Landsat Thematic Mapper (30 metre resolution) would detect changes within most features. However, detailed analysis of landcover succession and recession over short time periods (1-2 years) would necessitate the use of high resolution sensors.

Faunal contents and Their Contribution to Organic Matter Dynamics in Soils of the James Bay Lowlands

A.D. Tomlin, R. Protz and D.C. McCabe

The Hudson and James Bay Lowlands are a consequence of crustal rebound since deglaciation. The lowland is extending laterally from a combination of rebound and sedimentation at a rate of 10 to 12 m/yr in the Hannah Bay region of James Bay. Soil pits and core samples for subsequent soil faunal analysis were taken along a transect 400, 650 and 1100 m orthogonal to the coast 2 km west of North Point, which is 70 km to the west of Hannah Bay. Soils on this transect were estimated to be between 40 and 100 years old. Microfaunal density and diversity was positively correlated with soil age or distance from the coast, and soil organic matter content.

The site at 1100 m on the transect harboured a significantly more diverse and dense assemblage of fauna, compared to the younger seaward sites, particularly with regard to springtails, mites, nematodes and rotifers. An exotic anthropochore earthworm species *Dendrobacna octaedra* (Annelida: Lumbricidae) was also collected at the 650 and 100 m sites respectively, and are first records of earthworms from this northerly and isolated region of Ontario (it has been previously postulated that native North American species of earthworms were eradicated by glaciation, and present Canadian earthworm fauna is mainly represented by recently imported exotic species).

Higher resolution sampling along such transects should make possible estimations of mean colonization rates of fauna in newly-formed soils. The unique properties of newly-forming soils, such as low organic matter accumulation, would appear to be boundary conditions lending themselves to the study of the contribution of soil faunata to soil-forming processes.
Use of $^{137}$Cs to Differentiate the Rate of Accretion from Crustal Rebound in Hannah Bay, Ontario

R. Protz, D.C. McCabe and A.D. Tomlin

The Hudson and James Bay Lowlands are the result of crustal rebound since deglaciation. The present rate of rebound has been measured at 0.76 cm per year. The accumulation of sediment from tidal deposits varies depending upon load. Sediment load within tidal water depends upon distance and direction from river mouths. It has been postulated that the maximum rates of sediment accretion occur in the Hannah Bay as the currents are forced to change direction due to the Precambrian outcrops on the east side of James Bay.

Three Gleysolic (Aquents) soil profiles were sampled on each of two transects orthogonal to the coast. Transects were located on the east and west side of the Harricana River, which flows into Hannah Bay. Relative elevation measurements were made on the transects and, thus, at each soil pit site.

The distribution of $^{137}$Cs within each of the three soil profiles was used to elucidate the rate of sediment accretion. If all the increase in elevation is assigned to uplift, the ages of the oldest profiles on each transect are 197 and 173 years (i.e. time since they emerged from the Bay). If an average accretion rate (1.14 cm/year) was accepted, the oldest soil profiles are 78 and 69 years. If these ages are correct, between 10 and 12 meters of new land is emerging from the Hannah Bay each year and is being colonized by vegetation and soil fauna. These transects can provide very useful outdoor laboratories for the measurement of the sequence of colonization by various species of vegetation and fauna over very recent times within the lowlands.

Early Post-Glacial Sediments and Environmental Changes of the Lower Permian of South Africa and Comparison with Those of the Quaternary of Canada

I.P. Martini and B. Cairncross

This research was conducted while Dr. Martini was at Afrikans University Park, Johannesburg 2000, South Africa on sabbatical from March-April 1991.

The objective of the research was to do a comparative analysis of the early post-glacial Permian-Carboniferous deposits of that country with those of similar age in other countries of the Southern Hemisphere (namely Australia and Brazil which have been visited by Dr. Martini over the last 7 years) and the Quaternary sediments of Canada which have been and are intensely studied here. The ultimate objective of all this research is the analysis of the global changes, which occur on parts of our planet from the onset of de-glaciation to the time of formation of peatlands and eventually to the development of subsequent semi-arid to arid conditions. This objective has intrinsic geological value in the Southern Hemisphere because some of these rocks contain coals used there in thermo-electric stations. It has also value in establishing the importance of the global climatic changes Earth is now experiencing, and in providing a possible scenario of what might happen by considering what has happened in Permo-Carboniferous times.

During the visit to South Africa, extensive literature research was completed, several open pit mines and several underground coal mines were visited and their rock sections studied. Furthermore, several rock cores were studied. Much information has been obtained from the coal-bearing units. A lesser amount of information was available from the critical units lying between the top of the glaciogenic diamicite and the coal layers themselves: it is a practice in South Africa to stop coring and mining at the base of the lowermost coal, and very few cores were obtained from deeper glacial units. The information is not as extensive and equally spaced as one would wish, but it is sufficient for a good comparative analysis between the Pleistocene-Holocene deglaciation events of Canada and the Permian ones of S. Africa. The interesting thing about South Africa is that, similar to Canada, it provides both continental deglaciation settings, with well developed peat-coal units just above the glacial beds, and continuous marine deglaciation settings, which are more common throughout the Southern Hemisphere.

The project is an ongoing one. As a byproduct of this visit and of previous ones to Australia and Brazil by Dr. Martini, an edited book for Elsevier is in preparation dealing with "Global changes occurring between the onset of de-glaciation and the development of early post-glacial peat-bearing environments".
Analysis of Paleosols and Overbank Deposits of the Blairmore Group (Lower Cretaceous), Crowsnest Pass and Adjacent Area, Southwestern Alberta

Paul J. McCarthy and I.P. Martini

The overall objectives of this investigation are to establish the presence, type(s) and degree of development of paleosols in these stratigraphic units, and to use paleosols to enhance the environmental interpretation of floodplains of the Lower Cretaceous Blairmore Group and, therefore, determine the internal drainage, climate and surface stability of these ancient landscapes.

Good exposures of the paleosol-bearing Lower Cretaceous Blairmore Group are present in the Crowsnest Pass area of southwestern Alberta. Field work during 1991 focussed on outcrop study of the Beaver Mines and Mill Creek Formations. Specific outcrops examined included Mill Creek, Mill Creek Bridge, Coleman, Bruin Creek, Vicary Ridge, Highwood Junction, Highwood River, Kananaskis, and Sheep River. These data, in conjunction with data collected during 1990, have allowed the separation of the rock sequence into four sedimentary facies associations, including fluvial sandy channel, proximal overbank with interlayered gray mudstone and sandstone, distal overbank with variegated mudstone, siltstone and sandstone, and paludal gray massive mudstones.

Superimposed on these sedimentary facies are a number of pedogenic features. Fluvial channel lags contain transported wood and plant fragments as well as shale clast pedorelicts (features derived from eroded soils) indicating the existence of pedogenized floodplains. Proximal overbank deposits contain weakly developed paleosols characterized by fine to coarse carbonaceous root traces. Poor paleosol development indicates frequent flooding and sediment deposition close to the fluvial channel. Distal overbank deposits contain more abundant and better developed paleosols indicative of more stable conditions farther from the channel. Typically, the paleosols contain fine to medium carbonaceous vertical root traces, often with pale olive reduction halos. Larger root moulds sometimes occur near the surface of thin sandstone beds. Clay films, blocky structure and fine motling are common. Paludal deposits contain both vertical and horizontal shiny carbonaceous root traces. Weak paleosol development in this environment is attributed to wetland conditions. No coal layers are found within the Blairmore strata, indicating sedimentologically active environments and, perhaps, insufficient moisture for peatland development. Other pedogenic features, including red colouration, iron nodules, and pyrite, may be related to pedogenesis but have been modified by diagenesis.

Paleosol analyses reinforce the sedimentological paleoenvironmental interpretation of these deposits. Where the paleosols are better developed, they provide additional information on floodplain stability (lack of erosion and sedimentation), local paleoclimate and drainage.

Paleoecology and Paleoclimate of Oligocene-Pleistocene Lacustrine Intramontane Basins of Central and Northern Apennines, Italy

I.P. Martini and M. Sagri

This research was initiated in October/November.

The objective of the study was to establish the evolution of extensional basins of the Northern Apennines of Italy, to the west of the main thrusted bulge or the mountain chain. This system is a typical extensional-compressive mountainous arc similar to several others of the peri-mediterranean region. The portion of the system presently lying on the mainland Italy, started forming in Late Miocene and continued to recent times. Its development stranded periods of great climatic and geological and physiographic changes in the area.

The basins have been affected by both structural uplift and sinking, by periods of semi-arid conditions which had their strongest expression during the Messinian "salinity crisis" of the Mediterranean, and the colder climates during the Pleistocene. Some basins have undergone strong subsidence leading to formation of up to 3000m of sediments, and have been subsequently uplifted with marine Plio-Pleistocene sediments now found up to 800 m above sea level. The sedimentary sequences are locally slightly tilted but never intensely folded.

These basins have good records of various structural events, paleoclimatic changes and eustatic sea level fluctuations.

The first task was to review the large amount of information (mainly in the form of maps, local geological report, and paleontological studies). The study of the sedimentology of selected basins (Fine Miocene, Monteguidi Miocene - Pliocene, Velona Miocene - Pliocene, Valdarno Pliocene - Pleistocene, Mugello Pleistocene) was conducted to obtain information lacking on their evolution. Particular attention was paid to topics such as the formation of various types of lignite, development of various
Influence of parent materials on soils and vegetation at the Ngualla carbonatite complex, Southwest Tanzania

P. van Straaten

It is well known that parent material, climate, relief, organisms, and time have a strong influence on pedogenic processes. Opinions differ, however, on the relative importance of the various factors under intensive tropical weathering conditions, especially on the importance of the factor parent material.

Soils and vegetation differ strongly in East Africa, and many researchers relate their distribution to either different climatic conditions or to relief. At first sight, the climate seems to be one of the major controlling factors in soil formation in the tropics. Prolonged weathering have largely homogenized the previously existing differences in parent materials leading to the enrichment in Al, Fe and Si, manifest in the wide distribution of oxisols and ultisols.

Since decades, exploration geochemists make use of subtle but nonetheless significant differences of trace elements in residual tropical soils in order to detect parent material signatures. In recent years, other rapid and cost effective tools have been added to delineate these differences: geobotanical and remote sensing surveys.

During an integrated phosphate exploration survey over carbonatites in SW Tanzania, carried out in the framework of the Tanzania-Canada agrogeology project, the relationships between soil parameters, landforms, parent materials, and vegetation types were studied in an area with strongly contrasting parent materials (carbonate-rich carbonatite vs silicate-rich meta-rhyolite). Other factors, like climate, relief, and time of soil formation were the same.

Results of these surveys show that the chemical and physical soil...
parameters, such as availability of Ca, Mg, K, P and trace elements, water holding capacities and soil depth, differ strongly over the differing rock types.

Also the vegetation pattern, specifically that of trees shows a clear contrast. The geobotanical mapping outlined the distribution of trees over and around the Ngualla carbonatite and showed a strong contrast in the distribution of miombo woodlands (characterized by a closed canopy tree association of Brachystegia-julbernardia species) and relatively open acacia vegetation was observed: "miombo" woodlands occur outside the carbonatite, acacia vegetation is found predominant inside the carbonatite complex. Trees and shrubs of the comretum-termitaria vegetation type are found over both, the carbonatite and the silicate rich meta-rhyolite (Fig. 1a).

The distribution of the tree vegetation is readily visible on the aerial photograph covering the Ngualla carbonatite (Fig. 1b).

The geobotanical and soil surveys show that, under the given East African conditions, strongly contrasting parent materials such as carbonates vs silicates have a distinct influence on the composition and distribution of overlying soils and on the tree vegetation, which can easily be distinguished on the ground and from the air. This distinction further illustrates the importance of using remote sensing techniques as relatively cheap and rapid exploration tools to find new occurrences of rocks of economic and agrogeological potential "hidden" under vegetation and soils.

The Guelph Pressure Infiltrometer Now Adapted to Measure Air and Water Entry Values

D.J. Fallow, D.E. Elbrick and N. Baumgartner

The Guelph Pressure Infiltrometer (G.P.I.) is a Mariotte-based, single ring infiltrometer allowing a flow rate \( Q \) to be measured at a constant applied head. The flow is allowed to proceed until a quasi-steady state has been reached, and a constant flow rate exists (this step may also be repeated for a series of applied heads). An approximate analytical solution (Eq. [1]) will determine which portions of the overall flow are due to the pressure, gravitational, and capillary components. The gravitational and pressure elements of the flow regime are assigned to the saturated region, whereas the capillary portion belongs to the unsaturated region. The hydraulic property associated with the saturated zone is the Field Saturated Hydraulic Conductivity \( K_s \), while the property associated with the unsaturated zone is the Matric Flux Potential \( \phi_m \).

\[
Q = \frac{a/G}{H + \pi a^2} K_s + \frac{a/G}{\phi_m} \tag{1}
\]

where

- \( Q \) is the flow rate \( (L^3/T) \)
- \( a \) is the ring radius \( (L) \)
- \( G \) is the mathematical shape factor (unitless)

Equation [1] contains two unknowns; therefore, it is not mathematically tractable in its existing form. Another piece of information is needed in order to solve for \( K_s \) and \( \phi_m \). At this point, there have been two options available to the investigator.

The first option is to collect data for a second applied head resulting in two equations with two unknowns. Problems may arise on some of the more heterogeneous sites as the second head flow regime maybe considerably different to that of the first, and the solution of the simultaneous equations may yield negative parameter values. The second option involves utilizing the \( \alpha \) parameter, which is the ratio of \( K_s \) to \( \phi_m \). The value of \( \alpha \) is assumed to be related to the texture/structure of the soil; therefore, an estimate may be made with consideration of the site, and the equation reduces to having one unknown. Hence, the possibility of producing negative parameter values is eliminated.

An alternative method in ascertaining \( \alpha \) is proposed which eliminates the need to estimate a value. In addition to the flow rate \( Q \), the field measurements include the Air Entry and Water Entry values. The Air Entry value pertains to the desorption curve, and is the tension at which air is first drawn out of a desorbing soil. The ratio of \( K_s \) to \( \phi_m(\alpha) \) was defined as approximately equal to the inverse of the Water Entry value, which in turn is equivalent to \( 1/2 \) the Air Entry value. Since measurement of the Water Entry Value (the tension at which the soil first becomes saturated during sorption) seemed too difficult, the air entry value, with its more direct approach, was used in determining the ratio.

With the methodology currently used, it will be possible to measure Water Entry as well as Air Entry values in the field. These measures will allow the operator of the G.P.I. to use more field information in solving for the hydraulic properties and hopefully produce more representative results.
The Use of TDR to Measure Soil Hydraulic Properties

G.W. Parkin, D.E. Elrick, R.G. Kachanoski and N. Baumgartner

A knowledge of the hydraulic properties of unsaturated soil systems is of fundamental importance to many disciplines including agriculture, hydrology, forestry, and engineering. For example, the determination of the overall effect of alternative tillage practices on soil surface infiltration is a prerequisite to en masse adoption of minimum impact agriculture. To this end, a new field procedure, which utilizes Time Domain Reflectometry (TDR) technology to measure the hydraulic properties of soils in situ, is proposed.

Time Domain Reflectometry (TDR) is a relatively efficient, accurate, and nondestructive technique to measure a spatially averaged volumetric water content ($\theta_v$). The technique is relatively insensitive to soil texture/structure, bulk density, and temperature. An electromagnetic pulse is propagated through the soil via a pair of parallel waveguides or TDR probes. The velocity of the wave in a soil-water medium is proportional to $\theta_v$.

Transient measurements of soil water storage ($W = \theta_v L$) to the depth of TDR probes are determined under artificial constant rainfall or constant water content inlet boundary conditions, where $W$ is cumulative storage and $L$ is TDR probe length. Recently, analytical solutions of Richards’ water flow equation under the former inlet boundary condition, were published. The solutions ($\theta_v(z,t)$) formed the basis for the integral calculation of cumulative soil water storage as follows:

$$W(L,T) = \int_0^L \theta(z,t) \, dz$$  \hspace{1cm} [1]

where $z$ is depth and $t$ is time. A change of the variable of integration in Equation [1] has yielded a quasi-analytical solution for $W(L,t)$.

The published solutions utilize empirical soil water diffusivity and hydraulic conductivity functions. The functions contain three hydraulic parameters: $K_s$, $\alpha$, and $C$. The parameter $K_s$ is an estimate of the in situ "saturated" hydraulic conductivity, generally considered to be less than the value at true saturation due to entrapped air. The $\alpha$ parameter gives an approximation of the change in hydraulic conductivity as soil water potential and water content are reduced. $\theta_v$ assumes $K_s > > K_v$, where $K_v$ is the hydraulic conductivity at incipient uniform water content. The parameter $C$ governs the shape of the advancing wetting front in soil.

A preliminary analysis of the $W(L,t)$ solution revealed a high sensitivity to all three parameters. As visible in Figure 1, $K_s$ has a profound, albeit physically plausible, effect on $W(L,t)$. Acquisition of equilibrium storage, which indicates complete passing of the wetting front beyond the depth of measurement $L$, is accelerated under high $K_s$ conditions. A nonlinear least-squares fitting procedure such as the Levenberg-Marquardt technique, may be used to determine "best-fit" values of $K_s$, $\alpha$, and $C$ from $W(L,t)$ field data.

![Figure 1. Effect of $K_s$ on cumulative storage. Note that the constant rainfall rate is $10^{-3} \text{ m/s}$, $\alpha = 12 \text{ m}^3$, $L = 0.2 \text{ m}$, $C = 1.5$, saturated volumetric water content = 0.4, and initial volumetric water content = 0.1.](image)

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A Computer Program to Analyze Solute Transport Data Collected with the TDR.

A.L. Ward and R.G Kachanoski

The variability of field solute transport parameters often demands a large number of samples for adequate description of a soil. This requirement can restrict the size of experiments because of labour and time requirements. Recently, a method based on Time Domain Reflectometry (TDR) was suggested to obtain solute transport measurements. The method is fast, accurate, inexpensive and nondestructive. This method has also been shown to be easily adapted to nonlinear least squares and time moment analyses for the estimation of transport parameters.

For large transport experiments (e.g. an experiment currently in progress will generate 4000 breakthrough curves (BTCs)), packages like SAS and MathCAD are time consuming and inconvenient. It was, therefore, necessary to develop a method that could accurately and efficiently handle large data sets. The end result is a program ECFIT written in FORTRAN 77 for IBM and compatible machines. The program offers an option for the type of BTC to be analyzed. The curve can be that derived from a pulse or step input. For the step input, there is an option for the classical error function concentration profile or its inverse. The raw EC vs. time data is read in after which it undergoes a user defined number of smoothings. Smoothing is necessary since taking the first derivative will amplify measurement errors. A subroutine is called to fit a cubic spline to the smoothed data. This routine offers an option of calculating the first or second derivatives or both. The first derivative gives the solute travel time probability density function (pdf) which is very important in the analyses of BTCs.

The following are calculated in another subroutine using the pdf: the area under the curve; the time for 50% of the mass to pass a given depth (mean travel time, or first moment); the time for the peak concentration to reach the same depth (modal travel time); the peak concentration; the variance of travel time (second moment) and the skewness and kurtosis of the distribution. The second moment can be used to calculate the dispersivity and dispersion coefficient for the soil. Figure 1 shows a typical curve of raw EC vs. time compared to the spline fitted data. Figure 2 shows the pdf of the data after smoothing once. Calculated parameters and moments compare well with those obtained by other methods. The program therefore offers a rapid and accurate method of analyzing large numbers of TDR measured BTCs.

Figure 1. Observed vs spline fitted data.

Figure 2. Pdf of TDR readings.
A Computer Simulation of Transport in an Unsaturated Soil with Variable Horizon Thickness

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

The importance of variability in the prediction of field solute transport is well documented. Most of the studies of the effects of variability on dispersion, especially in groundwater, have concentrated on the dependence of the dispersion mechanism on the spatial variability of saturated hydraulic conductivity. However, in many cases conductivity can be described deterministically, thereby increasing the importance of other sources of variability.

Previous studies have investigated the effect of surface flux, variable velocity and dispersion coefficients, as well as variable retardation coefficient. In field soils, an additional source of heterogeneity affecting contaminant transport may be the distribution of horizon thickness. Figure 1 shows the spatial distribution of horizon thickness along a transect at the Delhi Research Station.

The effect of variable soil properties can be easily investigated numerically through the use of Monte-Carlo techniques. The objective of this study was to conduct a Monte-Carlo analysis of the transport of a conservative solute, in a layered profile of variable column thickness, with flow perpendicular to the stratification.

Materials and methods

The soil profile was assumed to be comprised of three horizons of thicknesses \( L_w \), \( L_p \), and \( L_c \), where \( L_t = L_w + L_p + L_c \) and \( L_c \) is the depth to the water table. In order to simplify the present analysis, it is assumed that each layer has hydraulic and transport properties that are constant within the layer, and different from those of adjacent layers. The profile is divided into \( N \) parallel columns without consideration for the spatial autocorrelation of horizon thicknesses or transport properties. A steady flow field is established in the profile with a constant flux, \( q \), at the surface. Since \( q < K_w \), flow is essentially unsaturated and vertical downward leaching of solute occurs in each layer at a velocity \( u \), given by \( q/\theta \).

At each location in the horizontal plane, the flux concentration of solute \( C_i(z, t) \) for each layer can be described as follows:

\[
\frac{\delta C_i}{\delta t} = D_i \frac{\delta^2 C_i}{\delta z^2} - v_i \frac{\delta C_i}{\delta z} \tag{1}
\]

where \( t \) is the time, \( i \) represents different homogeneous layers up to a maximum of \( n \), and \( D_i \) is the dispersion coefficient of layer \( i \). Equation [1] is subject to the initial condition

\[
C_i(z,0) = 0 \quad z > 0 \tag{2}
\]

and the following exit boundary condition:

\[
\frac{\delta C_i(\infty,t)}{\delta z} = 0 \quad t \geq 0 \tag{3}
\]

The solution for \( C_i \) requires the Type I condition given as

\[
C_i(0,t) = \begin{cases} C_o & 0 < t \leq t_o \\ 0 & t > t_o \end{cases} \tag{4}
\]

For subsequent layers, the initial condition remains unchanged, but the surface boundary condition changes. The boundary condition at the inlet \( (z = 0) \) is identical to the exit concentration profile of the previous layer. This is written as

\[
C_i(0,t) = C_i(l_n, t) \tag{5}
\]

For the first layer, the solution to Equation [1], subject to Equation [2], [3] and [4], is given as

\[
C_i(z,t) = \begin{cases} C_i + (C_o - C_i) A(z,t) & 0 < t \leq t_o \\ C_i + (C_o - C_i) A(z,t) - C_o A(z,t_o) & 0 > t > t_o \end{cases} \tag{6}
\]

where \( A(z,t) \) is given by

\[
A(L_i, t) = \frac{1}{2} \text{erfc} \left[ \frac{L_A - V_1 t}{(4D_1 t)^{1/2}} \right] + \exp \left[ -\frac{V_1 L_A}{D_1} \right] \text{erfc} \left[ \frac{L_A + V_1 t}{(4D_1 t)^{1/2}} \right] \tag{7}
\]

where erfc is the complimentary error function.

The solution to Equation [1] for subsequent layers is derived as

\[
C_i(z, t) = \int_0^t C(L_j-1, \tau) h(z, t-\tau) \, d\tau \tag{8}
\]

where \( h(z,t-\tau) \) is the impulse response function of layer \( i \). For the flux averaged concentration, the impulse response function is given by

\[
h(L_i, t-\tau) = \frac{L_i}{(4\pi D_i (t-\tau)^3)^{1/2}} \exp \left[ -\frac{(L_i - V_i (t-\tau))^2}{4D_i (t-\tau)} \right] \tag{9}
\]

where \( L_i \), for \( i \), is the distance measured from the surface to the end of the \( i \)th layer. The impulse response function acts as a weighting function on the input \( C_i(l_n, t) \). The method for obtaining the final solution is to proceed one
layer at a time using the exit concentration of the previous layer, \( C_i(L_{i-1}, t) \), in the convolution with \( h(L_{i-1}, t) \) for the adjacent layer. The solute concentration profile at \( C_i(z,t) \) at any location \((x,y)\) can, therefore, be predicted by Equation [8].

The field average solute distribution entering the water table can therefore be determined by Monte-Carlo simulation using the probability density function of measured horizon thickness and Equation [8]. For each successive case, a realization of \( L_{\text{np}}, L_{\text{op}} \), and \( L_{c} \) is randomly drawn from the distribution of horizon thicknesses and Equation [8] is solved. The procedure was repeated \( N \) times and the field average concentration profile entering the water table was calculated as the mean \( C/C_0 \) over \( N \) columns. The expected value of travel time over \( N \) Monte-Carlo runs was calculated by [10].

\[
E[t_{L_c}] = \frac{1}{N} \sum_{n=1}^{N} (t_{L_c})_n [10]
\]

Results and Discussion

Figure 2 shows the comparison of the breakthrough curve using a mean \( B_i \) thickness of 0.40 m and that obtained with a mean \( B_i \) of 0.40 and variance of 0.22 m². Time moment analysis indicates an increase in the mean travel time and dispersion when horizon thickness is treated as a random variable.

Conclusions

Treating a natural field soil as a perfectly layered may lead to erroneous predictions of solute travel time and dispersion. These will be compounded when the effects of spatially variable dispersivities, velocities and retardation coefficients

A Laboratory Study of Dispersion in Layered Unsaturated Soils

A.L. Ward and R.G Kachanoski

Layered soils occur in most natural settings. Although perfect layering over large distances is seldom found in nature, soils are often treated as such in attempts to explain the mechanisms of solute transport in heterogenous media.

The dispersion of solute in layered porous media, with flow parallel to layering, has been widely studied under saturated conditions. The same is not true for the unsaturated zone, where flow is perpendicular to layering.

Previous studies on variability have investigated the effect of random surface flux, variable velocity and dispersion coefficients, and variable retardation coefficient. However, an additional source of heterogeneity in layered soils may be the distribution of horizon thickness.

The motivation of this research was twofold. Firstly, the develop-
ment of mathematical models to predict field scale transport in the unsaturated zone is limited by the lack of accurate and reliable data on hydraulic and dispersive parameters, in view of extreme variability. Secondly, it is necessary to determine the relative importance of variable horizon thickness on dispersion.

In order to study dispersion in a natural layered soil, 50 undisturbed cores of 1.5 m length were obtained from a 20 m transect at the Delhi Research station. The soil is Fox sandy Loam with mean Bm horizon thickness of 0.4 m, but exceeding 3.0 m in some cases. These cores were instrumented with Time Domain Reflectometry (TDR) probes for the measurement of water content and electrical conductivity as well as miniature tensiometers for pressure head measurements (Fig. 1). Instruments were installed at 0.10 m increments from the surface.

The experiment involves applying 5 rates of water under constant flux at the surface until steady state is achieved. The approach to steady state will allow characterization of hydraulic parameters. At steady state, a pulse of solute will be applied and TDR measurements will allow characterization of transport parameters.

Overall, the experiment will provide a comprehensive data set of hydraulic and transport parameters through an unsaturated layered soil under spatially uniform boundary conditions. This data set will be used to evaluate the validity of a 2-Dimensional Finite element flow and transport model which has been developed for layered soils. In addition, it will provide estimates of scale dependence of dispersion in the unsaturated zone.
Susceptibility of Ontario Soils to Compaction and Compaction Risk Assessment: An Update

D.W. Veenhof, R.A. McBride and P. Joosse

A soil compaction research project (January 1991 to March 1993), which has the broad objective of modelling the relative susceptibility of agricultural soils in southwestern Ontario to compaction and applying compaction risk probability functions, is now nearing completion of its first year. Funding has been provided by the NSCP soil quality program (Project 9 - soil structure). The study seeks to link soil compression data from extensive oedometer testing in the lab with soil consistency-compressibility relationships already derived for soils in this part of the province. A soil water regime model (SWATRE) is further being calibrated for a corn production system and is to be used with long term climatic records to ascertain the risk of traffic-induced compaction at several key times during the corn growing season.

Twelve monitoring sites were selected in corn fields in early 1991 within the Regional Municipality of Halldimand-Norfolk. The soils at these locations encompassed the major soil associations where corn is grown in the region. The sites were also close in proximity, and on similar landscape positions, to several of the established O.I.P. groundwater table monitoring stations in the region. Early season installation of dedicated groundwater table observation wells and adjoining neutron thermalization access tubes allowed monitoring of the soil moisture extraction and recharge patterns through the 1991 growing and harvesting season. Field sampling at each site included taking replicate intact soil cores (for moisture retention and compression testing) and bulk samples (for chemical and physical characterization) from three depths in the upper 40 cm of the root zone. Field-saturated hydraulic conductivity measurements were also taken as required by the SWATRE model.

The uniaxial compression data from all soils (saturated and unsaturated) will be fitted to a non-linear moisture-density stress function, and from this both the compression index (slope of the virgin compression line) and the preconsolidation stress will be determined. An important aspect of this study is to examine the correspondence between the normal consolidation line from slurry consolidation and the virgin compression line from compression of saturated, structurally intact soils. Based on the simplifying assumption that these are similar, a soil survey interpretative method has been developed and tested by assembling physical characterization data on 228 agricultural soil horizons from a 5-county region along the north shore of Lake Erie. Analysis of variance showed that the "first approximation preconsolidation stress" for these horizons increased significantly with depth and with increasingly finer particle sizes. The highest mean estimated preconsolidation stress was about 270 kPa for the very fine clayey C horizon grouping, suggesting a badly over-consolidated condition.

Changes in Structural Stability Under Forages Relative to Continuous Corn Production

E. Perfect and B.D. Kay

Crops are normally rotated to maintain a good soil structure. The length of time a particular crop can be grown depends upon the rate of structural change under that crop, compared to the rate of change under the previous crop. Data on rates of change of soil structure under different crops are inadequate.

An experiment was conducted at the Elora Research Station to determine rates of structural improvement under alfalfa, bromegrass (high and low N), red clover (single and double cut) and minimum-till corn. The experiment was established in the spring of 1985 on a silt loam soil, previously used for conventional-till corn production. This treatment was included as a control. The plots were sampled at monthly intervals for 3 growing seasons. In the spring of 1988 the soil was returned to conventional-till corn production. The original experimental design was re-established. Sampling continued at monthly intervals over the next 2 growing seasons in order to quantify rates of structural deterioration.

Wet sieving and turbidimetry were used to assess changes in structural stability over time. Wet sieving measures the stability of aggregates >250 μm (WAS), and turbidimetry measures the dispersion of the clay fraction (DC). Both analyses were made on the same sample with the same energy input (end-over-end shaking in water for 10 min). Samples were pre-wetted by capillarity to reduce slaking. In the case of WAS, a correction was made for the presence of sand grains. The DC was expressed as a percentage of the total clay content. The soil water content at time of sampling (W) was also measured.

Monthly fluctuations in structural stability within a cropping treatment were as large, or larger, than changes obtained between crops over several years. Structural stability was closely related to the soil water content at time of sampling. The WAS decreased and DC increased, as W increased. A crop may exert an indirect effect on stability through its control of the soil moisture regime.
Regression analyses were used to remove the influence of \( W \) on WAS and DC.

To remove other (unexplained) sources of variation, the adjusted data for conventional-till corn were subtracted from the adjusted data for each crop. The differences were then expressed in terms of "half lives." The half life for structural decay is the time required for a crop to decrease structural stability to a point halfway between the initial and minimum levels. The half life for structural decay is the time required for a crop to decrease structural stability to a point halfway between the initial and minimum levels.

The minimum-till corn and red clover (single and double cut) treatments showed no significant improvement in terms of WAS for the period 1985-87. For DC, the bromegrass (low N), minimum-till corn, and red clover (double cut) treatments showed no significant improvement. Half lives for those treatments showing significant improvements ranged from 2.9 to 5.2 years for WAS, and from 3.7 to 5.1 years for DC. There were no significant differences between crops or stability parameters. Thus, the data were pooled giving an average half life of 4.5 ± 0.8 years for structural improvement.

The half-lives for structural decay under conventional-till corn (1988-89) ranged from 0.02 to 0.60 years for WAS and from 0.03 to 0.71 years for DC. There were no significant differences between crops or stability parameters. The average half life for structural decay (in those treatments showing a significant improvement in stability) was 0.2 ± 0.3 years.

The rate of increase in structural stability was much slower than the rate of decrease. Thus, most of the improvement achieved after 3 years of forages was lost within a few months of renewed conventional-till corn production (Fig. 1). Including forages in a rotation under these conditions may do little to enhance soil structure. Instead, alternative cropping and tillage practices that will maintain or improve structure on a continuous basis should be investigated. One such approach that we are currently exploring involves under-seeding red clover into corn.

![Diagram showing equations for FORAGE and CORN stability](image)

Figure 1. Predicted changes in structural stability under a forage relative to corn, where \( t \) is time since planting, \( \Delta \) is the difference in structural stability between the forage and corn adjusted for differences in water content, \( \Delta_{\text{max}} \) is the maximum possible difference in structural stability (19.1 for WAS and -2.5 for DC), \( a \) and \( b \) are rate constants (in 0.5/4.5 and in 0.5/0.2, respectively), and the subscripts \( \uparrow \) and \( \downarrow \) denote increasing and decreasing structural stability, respectively.

### Estimating the Fractal Dimension of Soil Aggregates from Mass-Size Distribution Data

_E. Perfect, B.D. Kay and V. Raisah_

The fractal dimension, \( D \), is defined by the following relationship between number and size:

\[
N_x = kx^{-D} \tag{1}
\]

where \( x \) is length, \( N_x \) is the cumulative number of objects greater than \( x \), and \( k \) is a constant. In most soils applications, it is the mass-size distribution that is determined. Assuming the shape and density of objects is scale-invariant, the fractal dimension can also be estimated from the mass-size distribution:

\[
\sum \frac{M(x)}{x^2} = c x^D \tag{2}
\]

where \( M(x) \) is the mass of objects of length \( x \), and \( c \) is a constant. Variation in shape or density as a function of size may introduce errors in the calculation of \( D \) using Equation [2].

The fractal dimensions for 46 aggregate size distributions, computed using Equation [2] (referred to as \( D_{\text{agg}} \)), were compared with those computed using Equation [1] (referred to as \( D_{\text{num}} \)). Samples were subjected to both dry and wet sieving. The mass-size distribution was determined gravimetrically. The number-size distribution was obtained by manual counting. We are currently investigating the use of seed counters to count aggregates automatically.
The aggregates produced by dry sieving were later dispersed. The primary particles within each size fraction were counted. These numbers were then subtracted from the numbers obtained previously. The fractal dimension was recalculated using Equation [1] (referred to as $D_{\text{cor}}$). A highly significant 1:1 relationship was found between $D_n$ and $D_{\text{cor}}$ (Fig. 1). Thus, no correction is needed for the presence of primary particles.

For the full data set, $D_n$ ranged from 0.67 to 3.92, while $D_m$ ranged from 0.79 to 4.06 (Fig. 2). Regression analysis revealed a highly significant linear relationship between $D_m$ and $D_n$. The intercept and slope were not significantly different from zero and one, respectively. It follows that the assumption of scale-invariant shape and density is valid, at least over the range of scales considered in this study ($7.5 \times 10^{-4}$ to $2.4 \times 10^{4}$). Within this range, the fractal dimension of soil aggregates can be estimated from mass-size distribution data uncorrected for primary particles.

$D_n = 0.99 \pm 0.01 \times D_{\text{cor}} + 0.02 \pm 0.01$

$R^2 = 0.994$

**Figure 1.** $D_n$ versus $D_{\text{cor}}$ for the dry sieving data. The diagonal represents the 1:1 line.

$D_m = 1.01 \pm 0.04 \times D_n + 0.13 \pm 0.20$

$R^2 = 0.935$

**Figure 2.** $D_m$ versus $D_n$ for the dry and wet sieving data combined. The diagonal represents the 1:1 line.
Assessment of a New Mass-Based Model for the Estimation of the Fractal Dimension of Soil Aggregates

V. Rasiah, B.D. Kay and E. Perfect

Structural stability is a measure of the ability of soil to retain the structural form over time against external forces of destabilization. The extent to which soil aggregates undergo fragmentation depends on stability of aggregates. Thus, the characteristics that describe fragmentation can provide a relative measure of stability. The parameter fractal dimension (D) has been recently used to characterize the influence of the factors affecting fragmentation of soil aggregates. Until recently, the number-size relation model has been used for the estimation of values for D. However, the aggregate number required to compute D has to be calculated from soil mass data. In this calculation, the bulk density (ρ) and shape of aggregates have been assumed to be scale invariant. These assumptions can have a finite influence on the computed values of D. The objectives of this study were to (a) develop a mass-based model for the estimation of D assuming only shape is scale invariant and (b) compare these values with those obtained using previously published procedures.

Values for D, assuming the use of scale invariant shape and ρ, were obtained using the previously published mass-size model:

$$\log M(x < X_j) = \log k_2 + k_1 \log x$$  \hspace{1cm} [1]

where $M$, $X_j$, and $x$ are the mass of aggregates on each sieve from the bottom to the top of the nest of sieves, the size of the largest aggregate, and the size of aggregate to which $M$ was cumulated, respectively. The parameters $k_1$ and $k_2$ are regression constants, with $D = 3-k_1$. The $D$ obtained using Equation [1] was abbreviated to $D_P$. However, in this model an upper limit was set to the values of $D_P$.

The following number-size relation was also used for the estimation of $D$ values,

$$N_i = c \bar{x}^{-D}$$  \hspace{1cm} [2]

where $N_i$ is the cumulative number of aggregates remaining on sieves from the top ($i = 1$) down to the $i$th sieve in the nest of sieves (i.e., $N_i = \sum_{i=1}^{j} n_j$), $\bar{x}$ is the mean size of aggregates on the $i$th sieve, and $c$ is a constant. Values for $\bar{x}$ are equal to $(x_{i} + x_{i+1})/2$, and $x_{i}$ is the size of mesh openings in the $i$th sieve. The value of $D$ is equal to the slope of the best fit of $\log N_i$ vs. $\log \bar{x}$. Equation [2] was fitted using manually counted and computed aggregate numbers. The preceding two values of $D$ will be referred to as $D_n$ and $D_c$, respectively.

We propose the following mass-based fractal probability model for the estimation of $D$:

$$P_i + \sum_{i=2}^{\infty} (1-P_{i}) \prod_{i=2}^{\infty} P_{i(i-1)} = u x_{i}^{-D}$$  \hspace{1cm} [3]

where $u$, $N_i$, and $P$ are the constant, the product of $P$ from $P_1$ to $P_{i-1}$, and probability of failure, respectively. For example, when $i=4$ the product $\prod_{i=2}^{3} P_{i(i-1)}$ is equal to $P_1 \cdot P_2 \cdot P_3$. The scale invariant $p$ assumption does not have to be invoked as long as $P$ can be measured independent of $p$. Furthermore, no limits to the values of $D$ are set. The log-transformed values of the terms on the left hand side of Equation [3] were regressed against $\log x_i$ to obtain the estimates for $D$ and $u$. The $D$ obtained using Equation [3] is abbreviated $D_m$. The probability of failure was calculated using the following equation:

$$P_i = \frac{w_i}{W_i}$$  \hspace{1cm} [4]

where $w_i$ is the oven-dry mass of the aggregates placed on the sieve with mesh openings of $i$ mm, and $W_i$ is the oven-dry mass of aggregates remaining on that sieve after wet sieving. The measurement was repeated for other different aggregate sizes.

Aggregate size distribution and $P$ during wet sieving, as a function of size for three soils, were obtained using a modified form of the Yoder apparatus. Significant linear correlations existed between $D_n$ and $D_c$, and between $D_n$ and $D_m$. The linear correlation between $D_n$ and $D_c$ was significant but not $1:1$. This result was probably due to the upper limit of 3 placed on the estimates of $D$ obtained using Equation [1]. The linear correlation between $D_n$ and $D_c$ was also significant but not $1:1$. The $D_n$, $D_c$, and $D_m$ were strongly influenced by soil, cropping treatment, and the estimation model used. Selected soil properties (clay and organic matter (OM) contents) explained 70, 52, and 47% of the variability in the values of $D_m$, $D_c$, and $D_n$, respectively. This relationship suggests that soil survey data can be used for the computation of values for the fractal dimension. The values for $D_m$, $D_c$, and $D_n$ increased with decreasing clay and OM contents, suggesting the number of potential failure zones decreased with increasing clay and OM contents. The values of $D_n$ compared well with $D_c$ and accounted for the highest amount of variability due to clay and OM contents of the soils.
Scaling the Variations in Structural Stability of Moist Soil Aggregates with Water Content at Sampling

V. Rasid and B. D. Kay

Structural stability is a measure of the ability of soil to retain the structural form over time against external forces of destabilization. When measurements on stability were carried out on field moist aggregates, the measured stability values were found to be strongly influenced by water content (θ) at sampling even when slaking was minimized. Comparison of cropping influence on the stability of different soils requires a tool that will account for the variations due to θ at sampling. Scaling is a powerful tool that can be used to study the variations in stability with θ at sampling of different soils. Scaling is a means by which the stability of different soils can be related to one another by simple conversion factors called scale factors. The objective of this study was to investigate the applicability of the function normalization technique (FNT) to scale the variations in wet aggregate stability (WAS) and dispersive clay (DC) at sampling of 10 different soils.

The WAS and DC measurements for field moist soil aggregates were carried out using a combination of wet sieving and turbidity methods. A linear dependence on θ was found for both stability parameters. The slope and intercept of each stability function were significantly correlated. The scale factor, $k_\theta$, for the WAS(θ) function varied from 0.43 to 1.57 and that for the DC(θ) function, $k_\delta$, varied from 0.33 to 1.81. Scale factors > 1.0 indicate that WAS and DC at a given θ are less than that of the reference line which has a scale factor < 1.0. Conversely, scale factors < 1.0 indicate that WAS and DC are greater than that of the reference line. The scale factors for five out of the ten soils were > 1.0. These soils were either coarse textured or had been under conventional corn/soybean production for more than 10 yr. We show that $k_\theta$ and $k_\delta$ depend on selected soil properties and these properties accounted for 68 and 82% of the variability in $k_\theta$ and $k_\delta$, respectively. These relationships suggest that soil survey data can be used to compute scale factors, thereby extending the usefulness of soil survey data to scale the variations in WAS and DC with at sampling. The values for the scale factors decreased with increasing clay and organic matter contents of the soils.

The relative efficiency of scaling (RES) for WAS(θ) was 77, and that for DC(θ) it was 78%. The RES for the coarse textured soils was < 18% compared to 84% for the fine textured soils. The correlation between $k_\theta$ and $k_\delta$ was relatively poor ($r = 0.64$), indicating the scale factors were probably specific to the function for which they were computed.

The results show that the variations in WAS and DC due to θ at sampling can be scaled using FNT. The efficiency of scaling of the computed scale factors was greater than 75%, i.e. the scale factors were sufficiently accurate to scale the variations in WAS and DC with θ at sampling. Finally, we show that soil survey data can be used to compute scale factors, thereby extending its usefulness.

Some Experimental Results Concerning the Influence of Clay Mineralogy on Aggregate Stability

J.A. Rombang and P.H. Groenevelt

Soil aggregate stability affects soil erosion and soil physical behaviour. The stability of a soil aggregate is related to its constituents, such as organic matter, clay, sesquioxide, Ca-carbonate, and adsorbed ions. The experiment of concern emphasized the role of clay mineralogy on aggregate stability. The objective was to find out whether different clay types have different effects on aggregate stability, and to investigate the mechanism by which clay mineralogy affects aggregate stability.

Soil samples were taken from five different sites in Indonesia. They are Katahan soil (RA), Toliat soil (TO), Kakasan soil (KA), Tjibadak soil (TB), and Toraut soil (TR). They are not under intensive tillage except the Kakasan soil (KA). The five soil samples were air dried and sieved. The 1-2 mm soil aggregates were collected for Water Aggregate Stability (WAS) measurement.

The clay mineralogy was analyzed (Table 1). Amorphous clay minerals, kaolinite, and halloysite were present in the clay fraction of soil RA. Both soil TO and soil TR consisted of kaolinite and smectite. Soil KA was dominated by amorphous clay mineral, while soil TB was dominated by kaolinite and there was a trace of clay mica.

The modified Yoder’s method was used to measure WAS. However, the soil was immersed directly into the water without prewetting under vacuum. The percentage of WAS was calculated from:

$$WAS = \frac{\text{Sample Wt. (after wet sieving) - Sand Wt.}}{\text{Initial Sample Wt. - Sand Wt.}} \times 100\%$$
The data of WAS was analyzed statistically as a one-way classification analysis with covariates (clay and organic matter content). Clay type was the main variable with the percentage of organic matter and clay content as covariates. Clay content was not significant, so it was rejected as a covariate (Fig. 1). Organic matter content was significant and was retained as a covariate (Fig. 2). The best fitting model for the data is:

\[
\text{WAS} = \text{Clay type} + 53.37 \ln(\text{OM}) - 15.66 (\ln(\text{OM}))^2
\]

After adjusting the data of WAS for the effect of organic matter, the percentage of WAS for each soil or each predominant clay type (Fig. 3) showed that soil RA, TO, KA, and TB were not significantly different from each other, but soil RA, TO, and KA were significantly different from soil TR. The higher aggregate breakdown of soil TR compared to other soils was likely due to the differential swelling of smectite within the matrix of the aggregates. It has previously been shown that aggregates formed from smectite were more subject to slaking than aggregates formed from non-swelling clay minerals.

Although smectite is present in soil TO, the impact of differential swelling could be overcome by the presence of iron and aluminum oxides. Aluminum and iron oxides promote aggregate stability by decreasing clay swelling. Table 2 shows that the aluminum oxide content in clay fraction of soil TO was higher than that of soil TR.

![Figure 1](image1.png)  
**Figure 1.** Relationship between water aggregate stability (WAS) and clay content.

![Figure 2](image2.png)  
**Figure 2.** Relationship between water aggregate stability (WAS) and organic matter content.

![Figure 3](image3.png)  
**Figure 3.** The effect of clay mineralogy, as found in each soil site, on water aggregate stability (WAS).
Table 1. Clay Mineralogical Analysis

<table>
<thead>
<tr>
<th>SOIL ID</th>
<th>PREDOMINANT (50 percent)</th>
<th>PRESENT (10-50 percent)</th>
<th>TRACE (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratahan</td>
<td>Kaolinite Halloysite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOliang</td>
<td>Kaolinite</td>
<td>Amorphous clay</td>
<td></td>
</tr>
<tr>
<td>Kakasen</td>
<td>Amorphous clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tjadadak</td>
<td>Kaolinite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toraut</td>
<td>Smectite</td>
<td>Kaolinite</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Iron and Aluminum Oxides in Clay Fraction

<table>
<thead>
<tr>
<th>Soil</th>
<th>%Fe</th>
<th>%Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>2.32</td>
<td>6.31</td>
</tr>
<tr>
<td>TO</td>
<td>1.54</td>
<td>5.19</td>
</tr>
<tr>
<td>KA</td>
<td>4.01</td>
<td>6.38</td>
</tr>
<tr>
<td>TB</td>
<td>0.96</td>
<td>7.68</td>
</tr>
<tr>
<td>TR</td>
<td>1.46</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Boron Adsorption on Humic Acid

Junning Hou and L.J. Evans

Interactions between boron and organic materials, such as humic substances, determine to a large extent the bio-availability and mobility of boron in soils. Complexation of boric acid with organic ligands in aqueous solutions has been previously studied, and the formation constants for 1:1 and 1:2 complexes of borate or boric acid with some complexant organic ligands have been determined. Much remains to be learned about the nature and the extent of the reactions of boron with humic acid fractions.

Variable charge sites are found in humic materials. These sites arise from the dissociation of carboxylic acid and phenolic functional groups within the humic structures:

\[
\text{R-COOH} \rightleftharpoons \text{R-COO}^- + H^+ \quad K_{a1} \tag{1} \\
\text{R-OH} \rightleftharpoons \text{R-O}^- + H^+ \quad K_{a2} \tag{2}
\]

These functional groups in humic acid can form strong complexes with boron. Carboxylic acids typically have acidity constants, pK_a's, around 3 to 5, depending on their configuration. Phenolic groups are generally much weaker acids than carboxylic acids, but are similarly abundant in humic acid fractions. In addition, cis-diol and -hydroxy-carboxyl groups have also been proposed as two other major boron adsorption sites and are known to be capable of protonation-dissociation and ligand-exchange reactions. This interaction has been shown to be pH dependent and increases as the pK_a of boric acid is approached. The acid-base properties of hydroxyl-carboxyl groups on humic acid may be characterized by equations such as:

\[
\text{R}_2H_2^+ \rightleftharpoons \text{R}_2H + H^+ \quad K_{a1} \tag{3} \\
\text{R}H \rightleftharpoons \text{R}^- + H^+ \quad K_{a2} \tag{4}
\]

where RH^+ and RH represent protonated surface sites, and where RH^+ and RH are not necessarily the same group.

The question to be addressed is: what is the nature and the extent of the interactions between boron and the binding sites on humic acid?

As a preliminary investigation into interactions between boron and humic acid, experiments were conducted to assess the importance of boron concentration, pH and different electrolytes on the retention of applied boron. Boron adsorption isotherms were carried at pH 9.2, 0.5 in a batch system. The humic acid used in this experiment was extracted from a forest soil and was purified to have an ash content less than 1%. The initial concentrations of humic acid were at 0.3, 0.5 and 1.5 kg m^-3 and the initial concentration of boron ranged from 0.0925 to 46.25 mM. The adsorption isotherms obtained are shown in Figure 1. The retention of boron conforms to the Freundlich adsorption isotherm over the experimental pH range.

Boron adsorption experiments were carried out in the presence of different electrolytes. No significant difference was found between using 0.01 M LiCl and 0.01 M LiClO_4 as electrolytes. However, no adsorption occurred when the solution pH was below 6.8, and 0.01 M LiClO_4 was employed as the electrolyte. This difference may be caused from changes of the binding sites on humic acid by using the strong oxidizer, LiClO_4.

To investigate the adsorption of boron as a function of pH, adsorption experiments were conducted with an initial boron concentration of 1.067 mM, humic acid (Aldrich, MI) concentration of 4 kg m^-3 (dry weight) and at pH range of 4.2 to 10.5. The results are shown in Figure 2. Boron adsorption was found to increase from pH 4.2 to 8.5 and exhibit an adsorption peak within the pH range.
of 8.5 to 10, and decrease from pH 10 to 10.5. To explain similar results for boron adsorption on variable charge mineral surfaces, the formation of inner-sphere complexes has been suggested. Since the humic acid surface contains various functional groups, this approach for anion interaction may not be appropriate. However, the high ash content in the humic acid (32%) used influences the magnitude of boron adsorption.

A simplified modelling approach using boron complexation with organic ligands with different functional groups is shown in Figure 3. The model was based on the association constants between boron and organic ligands from the literature. The model curves do not fit the experimental data in Figure 2 very closely, as different shapes of the adsorption curve were obtained from the model calculations. However, an adsorption envelope was obtained by using catechol, with phenolic groups acting as the complexing functional group. This experiment implies that the phenolic group may be dominant in the humic acid employed.

Humic acid has multi-potential donor sites. Various functional groups may coordinate as a non-ionic (-OH) or ionic (-O-) groups, making it much more complicated and difficult to model anion complexation on humic acid. No workers have made an attempt to develop the stoichiometry for a system like boron with humic acid. Use of NMR spectroscopy ($^{11}$B and $^{31}$Cl) may help to establish the stoichiometry of such equilibrium reactions. Because the exchange of boron between the boric acid or borate complexes and free borate/boric acid is usually slow on a $^{11}$B NMR time scale, the species present in solution can easily be determined by their characteristic $^{11}$B NMR chemical shifts. The relative amount of the boronic acid and borate complexes can be determined by peak integration of the various signals. Further experiments will be conducted by using $^{11}$B NMR technique.

![Figure 1. Boron adsorption isotherm on humic acid.](image1)

![Figure 2. Boron adsorbed on humic acid as a function of pH.](image2)

![Figure 3. Boron adsorption on modelled humic acid.](image3)
Retention of boron by soils with high organic carbon contents

Juming Hou and L.J. Evans

Boron adsorption behaviour as a function of pH in soils has been previously investigated, but the soils chosen in those studies were low in organic carbon and high in oxides. Boron adsorption, thus, occurred primarily on oxide minerals and clay surfaces. The results were evaluated by various models, including the constant capacitance model. However, little information about B adsorption on soils with high organic carbon contents as a function of pH is available.

Boron adsorption is believed to occur through one or more mechanisms:

(i) adsorption of molecular \( B(OH)_3 \) onto mineral and/or organic surfaces;
(ii) anionic adsorption of \( B(OH)_4^- \) onto mineral surfaces through ligand exchange processes;
(iii) complexation with organic compounds containing cis-1, 2 and 1, 3 diol groups and carboxylic and phenolic functional groups; and
(iv) precipitation as inorganic mineral phases.

The solid components of soils may be coated with Al and/or Fe (oxy)hydroxides and oxides, or with organic substances, all of which tend to enhance adsorption characteristics. Boron adsorption on organic matter has been found to be significantly higher than that on clays at similar pH levels and total boron concentrations. Because of this evidence of the increasing importance of B complexation with organic ligands, soils with high organic carbon (up to 10%) were employed to study the interactions of B with both oxides and organic ligands.

Boron adsorption was conducted in batch systems on two soils where pH's were adjusted from pH 3 to 11. The soil samples employed in the study were from the Ap horizons of two Orthic Humic Gleysols: the Welland Series with 3.3% of organic carb-
on and the Cane Series with 10% organic carbon. The soils had similar clay contents of 48-50%. The soil solution ratio used in the adsorption experiment was 1:5 and the suspension density was 200 kg m\(^{-3}\).

Boron adsorption envelopes for both soils are shown in Figure 1. Similar shaped adsorption peaks in the pH range 8.2 to 9.2 were found for both soils. Retention of boron by the Cane soil showed higher adsorption throughout the whole experimental pH range of 3.5 to 11.2. These results indicate a positive relationship between soil organic matter content and boron adsorption. The results were compared with data on boron adsorption on humic acid (Aldrich, MI) conducted at the same electrolyte, but with different initial boron concentrations (Fig. 2). The pH range of the adsorption peaks for humic acid tended to be narrower and the adsorption envelope sharper than for the soils. The higher content of organic carbon in the Cane soil increased the amount of boron adsorption and also sharpened the adsorption peak. Compared with the adsorption envelope found for oxides, a relatively large amount of boron adsorption in the Cane and Welland soils was found at a low pH range of 3.5 to 5.5. This difference cannot be described by the constant capacitance model (Fig. 3). A further experiment is being conducted on the Cane and Welland soils to assess the specific effects of organic carbon on boron adsorption by using ultrafiltration techniques to separate organically-bound boron from the inorganically-bound boron.

Modelling Cadmium Retention in Soils

K.A. Bolton and L.J. Evans

The focus of our study is to develop a computer model to predict the adsorption behaviour of toxic metals by soils and sediments. As an initial part of this study, the retention of Cd by soil as a function of pH and metal concentration was investigated by adsorption experiments using a batch method. The pH values of the soils were adjusted by additions of HClO\(_4\) or LiOH to cover the pH range 3.5 to 8.0. Initial metal concentrations, [Cd\(_{\text{pp}}\)], ranged from 6.0 \times 10^{-5} to 2.1 \times 10^{-4} M and all equilibrations were performed in 10^{-2} M LiClO\(_4\). Concentrations of Cd over the pH range investigated were such that supersaturation with respect to hydroxide and carbonate phases was avoided. Results showed that the adsorption of Cd increased as a function of pH for all soils to reach maximum adsorption values of between 9 and 100 mmol Cd kg\(^{-1}\) soil.

Surface coordinating functional groups on soil particles behave as complexant ligands for metals in solution. As soils are composed of both mineral and humic fractions, surface complexation models for mineral surfaces and discrete functional group models for humic surfaces need to be considered in the development of a computer model. Complexation with organic colloidal material was modelled using a Humic Acid Model, HAM, in which it was assumed that there was one simple diprotic complexation site associated with humic materials. The dissociation reactions are:

\[
\text{H}_3\text{L} \rightleftharpoons \text{HL}^- + \text{H}^+ ; pK_{\text{al}} = 3.83
\]

\[
\text{HL}^- \rightleftharpoons \text{L}^{2-} + \text{H}^+ ; pK_{\text{a2}} = 4.92.
\]

The Cd complexation reaction was considered as:

\[
\text{H}_3\text{L} + \text{Cd}^{2+} \rightleftharpoons \text{CdL}^{\circ} + 2\text{H}^+ ; pK_{\text{Cd}} = 5.37
\]

where \(pK_{\text{Cd}}\) is the conditional complexation constant for Cd and humic acid. The model parameters for each soil also included [Cd\(_{\text{i}}\) and [H\(_3\text{L}\)]\(_{\text{i}}\), which were calculated from measured organic matter contents and a total organic matter acidity of 3.2 mol kg\(^{-1}\). Total acidity was assumed to be equal to the cation exchange capacity of the soil organic matter at pH 8.2. At this pH all protons associated with surface organic sites are thought to be dissociated.

Adsorption on variable charge mineral surfaces was modelled using the Constant Capacitance Model, CCM. The CCM is used for describing adsorption at mineral surfaces and assumes the formation of an inner-sphere complex between the metal and the surface site. An initial assumption was that the inorganic variable charge surfaces were associated with the mineral goethite. The intrinsic dissociation reactions for goethite considered were:

\[
\equiv\text{Fe-OH}_2^+ \rightleftharpoons \equiv\text{Fe-OH}^+ + \text{H}^+ ; pK_{\text{int}} = 7.0
\]

\[
\equiv\text{Fe-OH}^+ \rightleftharpoons \equiv\text{Fe-O}^- + \text{H}^+ ; pK_{\text{int}} = 11.0
\]

and the complexation reaction was described by:

\[
\equiv\text{Fe-OH}^+ + \text{Cd}^{2+} \rightleftharpoons \equiv\text{Fe-O-Cd}^+ + \text{H}^+ ; pK_{\text{int}} = -0.47
\]

where \(pK_{\text{int}}\) is the conditional intrinsic complexation constant for Cd and goethite. Additional parameters used for the CCM were [Cd\(_{\text{i}}\)] suspension density, specific surface, a site density of 16.8 sites nm\(^{-2}\) and a capacitance, \(K\), of 0.66 F m\(^{-2}\).
Local and Regional Estimates of Sensible and Latent Heat Flux Densities from a Patch-work Surface

A.G. Barr, T.J. Gillespie and K.M. King

Regional, surface sensible and latent heat flux densities (H and LE) are important in climatology and hydrology. This study assesses the feasibility of estimating day-time H and LE from surface and upper-air weather data. The regional, upper-air estimates are compared with local, surface measurements above a surface patch-work of agricultural land and forest.

Local, surface H, LE and CO$_2$ flux density were measured above nearby deciduous forest and alfalfa by the Bowen ratio - energy balance method (both surfaces) and eddy correlation (forest). The day-time Bowen ratios (on average 0.15 forest and 0.17 alfalfa) and transpiration ratios (123 kg H$_2$O kg$^{-1}$ CO$_2$ forest and 135 kg H$_2$O kg$^{-1}$ CO$_2$ alfalfa) were similar above forest and alfalfa. On some days, nearly all day-time surface available energy ($R_{av}$-S) was used as LE, and H averaged to near zero.

Two approaches were used to estimate regional H and LE. The first used successive rawinsonde measurements of upper-air temperature and humidity. The second used an integral, convective boundary-layer (CBL) model, initialized by an early morning, upper-air sounding and then driven by hourly, surface temperature and humidity. Both approaches assumed that horizontal advection and subsidence were negligible, and that H and LE equalled the upper-air, integral storage changes of sensible and latent heat ($\Delta S_H$ and $\Delta S_L$), integrated to well above the CBL.

A third model assumed that the soil mineral and humic surfaces could be considered non-interactive and their combined complexing abilities additive. Comparisons were made between the experimental data and each of the three complexant models considered. The model results (Fig. 1) indicated that humic surfaces accounted for adsorption at acidic pH values and that variable charge surfaces associated with goethite accounted for adsorption at higher pH values. The combined model underestimated the extent of Cd retention at acidic pH's, even when relatively high values for the specific surface of goethite were used. Reasons for this underestimation are currently being investigated, but probably include formation of outer-sphere complexes on constant charge surfaces and the formation of inner-sphere complexes at the edges of phyllosilicate clays.

Figure 1. Relative proportion, $\alpha_f$, of adsorbed Cd for a silty clay loam - experimental data and the three modelling approaches.

The 0700 to 1300 EST sum $\Delta S_H + \Delta S_L$ agreed closely with surface $R_{av}$-S when many periods were averaged or when periods were chosen where other budget terms were judged to be negligible. However, the upper-air, storage change Bowen ratio ($\Delta S_H / \Delta S_L$) was much higher than the surface Bowen ratio (e.g. 0.6 vs. 0.04 for Aug 3, 5 and 13, 1988). Two possibilities for this difference were identified and assessed:

(1) Other budget terms may have been important. However, none were definitively identified.

(2) The forest and alfalfa may not have been regionally representative. A surface energy balance - integral CBL model showed that, if the local patches of forest and alfalfa had atypically high canopy conductance, LE would be locally enhanced by the imposition of a warmer, drier CBL at the regional scale. This was judged to be the most plausible scenario.

Because $\Delta S_H$ was not estimated as reliably as $\Delta S_L$, the best way to estimate regional LE is as the difference between regional $R_{av}$-S and an upper-air, integral sensible heat budget estimate of H.
The Thermodynamic Basis for a Self-Acidulating Phosphate Fertilizer

W. Chesworth and P. van Straaten

Apatite, the basic raw material of most phosphate fertilizers, is a relatively insoluble mineral under most natural pH conditions. Only in relatively acid soils does it release phosphate fast enough to be used directly. In all other farmed soils the apatite must be treated to render it sufficiently soluble to sustain a crop. Apatite deposits are located in many tropical countries, but cannot be mined and processed because of their low grade, or their unreactive character. Fundamental research is being conducted by the agronology group to find methods to increase the solubility of apatites. Initial results of experiments using Tanzanian fluor apatites and Monocalcium Phosphate (MCP) blends indicate a possible in situ acidulation. Here we provide the theoretical basis for a self-acidulating process whereby apatite is mixed with MCP which, in contact with water, is capable of generating aqueous solutions with pH 1 to 2.

Figure 1 is a 25°C, 100 kPa cross section of the system CaO-P2O5-H2O. Solution of MCP in water would follow a path from A to D if no other equilibria were involved. In fact, the line AD crosses the stability field of monetite plus solution. Equilibrium is readily achieved between these phases and the solution path actually follows the equilibrium curve AB. This curve is the solution isotherm of other workers. Point B is an isothermal, isobaric, invariant point and represents the solution in equilibrium with monetite and MCP. Solution cannot move from this point while the two solid phases remain. Only when all MCP is consumed, is a change in the composition of the solution possible.

If a mixture of apatite and MCP is brought into contact with H2O, the apatite will inevitably react with solution B (pH approximately 1), produced by the dissolving MCP. The reaction path of the apatite will be produced whereby apatite will be converted to the bimineralic mixture apatite and monetite, and then, in closest proximity to solution, a monomineralic zone of monetite. The ultimate effect is to produce a monetite-coated apatite, with the monetite providing a faster release of phosphate to solution than the apatite it is replacing. The replacement reaction of monetite for apatite will continue until all MCP is used up. At this stage, the aqueous phase retracts its path from B to A and its acidulating capability is lost.

Petrographic and chemical studies are currently being conducted at LRS in conjunction with laboratory experiments using various apatite sources and various MCP/apatite blends.
Land Management
Comparison of Planters and Fertilizer Application Systems for Corn in Conservation Tillage

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

This project was initiated in response to difficulties being encountered with conventional fertilizer placement systems on no-till corn planters. To overcome these difficulties, farmers have made various modifications, most of which have involved mounting of additional coulters in front of the seed unit to till the soil in a strip into which the seed and fertilizer could be placed. We thought that three recent developments required further testing and direct comparison. These developments were as follows:

Cross-slot planter.

Workers in New Zealand have developed a new planting system, called the cross-slot planter (or T-slot planter), which places the seed and fertilizer with almost no disturbance of the soil below the seed and minimum disturbance above the seed. The developers claim that this system creates an ideal environment for germination and early growth of the seed. The fertilizer can be placed at seed level or slightly below and to one side of the seed. Jack Rigby, a farmer in Kent County has installed cross-slot planter units on a four row planter. This planter was used in our 1991 experiments.

Strip-band fertilizer application.

Recent studies at Guelph have indicated that higher corn yields can be obtained if the phosphorus absorption during early growth can be increased above that usually achieved with the conventional placement 5 cm to the side and 5 cm below the seed. A John Deere 7000 planter was modified to apply fertilizer in two strips (6.8 cm wide) on either side of and slightly below the seed. This planter has been used in field experiments in 1989, 1990 and 1991.

The objectives of the project were as follows:

a. To compare the effectiveness of planting and fertilizer application using the cross-slot and strip-band application systems.

b. To compare the cross-slot planter with a conventional system under varying soil conditions.

EXPERIMENTAL PROCEDURES

Experiments were conducted at two sites in 1989 and 1990 and three sites in 1991 (Table 1). The treatments varied from year to year and site to site depending on planter availability, P fertilizer requirement and planting conditions. The general approach involved comparisons of the different planters and placements at varying rates of fertilizer phosphorus based on the soil test. A check (no fertilizer), half the recommended rate and the recommended rate were included at all sites. All sites also included at least one rate and usually two rates greater than recommended. These ranged from 1 1/2 to 4 times recommended depending on the soil test.

RESULTS AND DISCUSSION

Side band vs. strip band

The corn yield at each of the two 1991 sites in which the side band and strip band were compared are presented in Table 2. It was not possible to use the strip band at the Huron County site because of a dense timothy mat. Although the strip band was slightly better than the side band at both sites, the differences were not significant at the 5% probability level. Yields were highly variable at the Rigby site because of moisture deficiency.

The means for the side band and strip band treatments in 1989 and 1991 are presented in Table 3. Because there was no response to P at either site, a comparison of the two placements in 1990 is not presented. The 1989 and 1991 results are quite consistent, with the strip band being slightly better than the side band.

The difference was significant at P = 0.07. The difference is probably the maximum that can be expected because the soils were very low in available P. Thus it is doubtful that the difference between the two placements justifies the major change in planters that would be required to achieve the strip band placement.

Comparison of cross slot planter with other planters

The cross slot planting system was included at three sites in 1991 in comparison with the Guelph experimental planter and, at two of the three sites, with the no-till planters used by the cooperating farmers (Jack Bigby in Kent County and Bruce Shillinglaw in Huron County). Comparisons involving the cross slot and Guelph planters included a check in which no fertilizer was applied, and two rates of 10-34-0 liquid fertilizer based on the requirements by soil test. Comparison with the Rigby planter was with no fertilizer only, while that with the Shillinglaw planter included a check and two rates using 10-34-0 in the cross slot and 13-52-0 in the Shillinglaw planters.

Grain yields for the different comparisons are presented in Table 4. There were no significant differences in grain yield between the cross slot and Guelph planters at any fertilizer rate at any of the three sites. The only significant difference in grain yield was between the Guelph and Shillinglaw planters when no fertilizer was applied. A similar observation was made in 1990 when the grain yields with the Shillinglaw planter were higher than those with the Guelph planter at all fertilizer rates. This difference was associated with a greater P concentration during early growth, even when no fertilizer was applied. This difference in early shoot P when no fertilizer was applied was also found in 1991 although the difference was not quite significant at a 5% probability level.

These differences between the Guelph and Shillinglaw planter may
be due to the effect of differences in soil disturbance on the vesicular arbuscular mycorrhizal symbiosis. Tillage has been found, in studies at Guelph, to decrease the effectiveness of the mycorrhizal symbiosis and hence decrease the absorption of P during early growth. The Guelph planter causes more soil disturbance in the planting row than the Shillinglaw planter.

The results with the cross slot planter are quite promising given that it was our first experience with it. With modifications to overcome some of the problems encountered, it has potential to be a superior planting system. The greatly reduced disturbance should maximize the effectiveness of the mycorrhizal symbiosis, which would reduce the amount of fertilizer phosphorus required at planting.

**Assessment of adequacy of fertilizer P recommendations**

Over the duration of this study (1989 to 1991), fertilizer phosphorus rates ranging from 0 to 2x that recommended according to the soil test have been applied at seven sites using the Guelph planter. With only one exception (Huron County-1990), all sites had a fertilizer P requirement of 50 kg P_2O_5 ha^-1 or higher. These sites, therefore, provide a useful evaluation of the adequacy of current recommendations based on the OMAF soil test. Data are presented for the side band application for three years at the Oxford County site in Table 5 and as a mean of all sites in each year in Table 6.

At none of the seven sites was there a response to fertilizer P application in excess of that recommended. Averaged over all seven sites, the recommended rate was the most profitable. In 1990 when the recommended rates were lower, there was no response to fertilizer P.

<table>
<thead>
<tr>
<th>Site</th>
<th>P_2O_5 (kg ha^-1)</th>
<th>Place</th>
<th>1/2 x</th>
<th>Rec</th>
<th>1 1/2 x</th>
<th>2 x</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kent</td>
<td>50</td>
<td>side</td>
<td>8.91</td>
<td>9.67</td>
<td>8.62</td>
<td>8.77</td>
<td>8.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>strip</td>
<td>9.41</td>
<td>9.79</td>
<td>9.80</td>
<td>9.14</td>
<td>9.54</td>
</tr>
<tr>
<td>Oxford</td>
<td>90</td>
<td>side</td>
<td>10.62</td>
<td>11.61</td>
<td>10.51</td>
<td>10.81</td>
<td>10.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>strip</td>
<td>11.30</td>
<td>11.50</td>
<td>10.92</td>
<td>10.94</td>
<td>11.17</td>
</tr>
</tbody>
</table>

These data indicate that even with low soil available P values, current recommendations are adequate. At medium soil test values, current recommendations may be greater than can be justified on an economic basis.

**Table 1: Placement experimental sites 1989-1991.**

**1989 - two sites**

- **ELORA RESEARCH STATION**
  - Silt loam
  - P test - 3 (L)
  - Previous crop - corn

**1991 - three sites**

- **HARTHOLM FARMS - OXFORD COUNTY**
  - Loam
  - P test - 6 (L)
  - Previous crop - soybeans

- **HARTHOLM FARMS - OXFORD COUNTY**
  - Loam soil
  - P test 12 (M)
  - Previous crop - soybeans

- **RIGBY FARM - KENT COUNTY**
  - Sandy loam
  - P test - 10 (M)
  - Previous crop - soybeans

**1990 - two sites**

- **BELLTANE FARMS - HURON COUNTY**
  - Loam
  - P test - 6 (L)
  - Previous crop - Timothy

- **HARTHOLM FARMS - OXFORD COUNTY**
  - Loam
  - P test - 9 (L)
  - Previous crop - corn

- **BELLTANE FARMS - HURON COUNTY**
  - Silt loam soil
  - P test - 18 (M)
  - Previous crop - red clover

**Table 2: Corn grain yields with a strip band and side band fertilizer application - means for 1991 sites.**
Table 3: Corn grain yield with a strip band and side band fertilizer application - means for 1989 and 1991 sites.

<table>
<thead>
<tr>
<th>Year</th>
<th>Place</th>
<th>1/2x</th>
<th>Rec</th>
<th>1 1/2x</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Side</td>
<td>7.80</td>
<td>8.42</td>
<td>8.42</td>
<td>8.21</td>
</tr>
<tr>
<td></td>
<td>Strip</td>
<td>8.05</td>
<td>8.49</td>
<td>8.99</td>
<td>8.51</td>
</tr>
<tr>
<td></td>
<td>Strip</td>
<td>10.6</td>
<td>10.65</td>
<td>10.36</td>
<td>10.46</td>
</tr>
<tr>
<td>Mean</td>
<td>Side</td>
<td>8.78</td>
<td>9.53</td>
<td>8.94</td>
<td>9.10</td>
</tr>
<tr>
<td></td>
<td>Strip</td>
<td>8.78</td>
<td>9.57</td>
<td>9.96</td>
<td>9.48</td>
</tr>
</tbody>
</table>

Table 4: Gain yields with different planters.

<table>
<thead>
<tr>
<th>Site/Planter</th>
<th>Fertilizer P rate</th>
<th>0</th>
<th>1/2x</th>
<th>Rec</th>
<th>2x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(t ha⁻¹ @ 15.5% moisture)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kent County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross slot</td>
<td>8.18</td>
<td>-</td>
<td>9.48</td>
<td>8.77</td>
<td></td>
</tr>
<tr>
<td>Guelph</td>
<td>8.60</td>
<td>-</td>
<td>9.67</td>
<td>8.85</td>
<td></td>
</tr>
<tr>
<td>Rigby</td>
<td>9.05</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard error of means = 0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huron County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross slot</td>
<td>6.18</td>
<td>7.63</td>
<td>8.01</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Guelph</td>
<td>5.62</td>
<td>7.12</td>
<td>7.91</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Shillinglaw</td>
<td>7.16</td>
<td>8.13</td>
<td>8.04</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard error of means = 0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxford County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross slot</td>
<td>9.58</td>
<td>10.33</td>
<td>10.61</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Guelph</td>
<td>9.20</td>
<td>10.62</td>
<td>11.61</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard error of means = 0.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Response of grain yield to fertilizer P in Oxford County (1989-1991).

<table>
<thead>
<tr>
<th>Year</th>
<th>Rec</th>
<th>P Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1/2x</td>
</tr>
<tr>
<td></td>
<td>(kg P₂O₅ ha⁻¹)</td>
<td>(t ha⁻¹ @ 15.5% moisture)</td>
</tr>
<tr>
<td>1989</td>
<td>50</td>
<td>7.99</td>
</tr>
<tr>
<td>1990</td>
<td>50</td>
<td>8.29</td>
</tr>
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A Field Experiment on the Effect of Various Tillage Systems on the Mycorrhizae and Phosphorus Nutrition of Maize

Terence McGonigle and Murray Miller

Disturbance of soil from long term no-till corn (Zea mays L.) plots reduces the phosphorus (P) absorption by young maize plants. There is evidence that such reductions in P absorption are caused by reduced development of the mycorrhizal associations of the root systems. Mycorrhizae develop more extensively when plants are grown in undisturbed soil cores brought in from the field, compared to their development in identical but disturbed cores. In an attempt to produce this effect under field conditions, we found the P absorption by maize at the 5- to 6-leaf stage from hand planted no-till plots, was significantly greater than from plots in which the soil was broken in aggregates less than 5 mm. In this report, we present part of a subsequent field study on the behaviour of mycorrhizae under various tillage systems in maize fields.

Shoot and root samples were collected weekly through the 1990 growing season from four replicates of each of four tillage treatments, in a long-term experiment at the Ridgeway College of Agricultural Technology in southwestern Ontario. The tillage treatments were sampled as follows: (1) Fall mouldboard plow and spring disked (MP); (2) Fall chisel plow (CP); (3) Ridge till (RT); and (4) No till (NT). These plots had received the same tillage treatments, and had
been under continuous corn cultivation, for the six preceding years. All treatments were fertilized at the same rate based on requirements as indicated by soil test. Samples were also taken at 15, 22, 29, 36 and 43 days after planting (DAP) in 1991. Root samples were taken as cores 7.2 cm in diameter and 15 cm deep at standardized positions in the row. The percentage of the root length containing arbuscules was determined by a line intersect method at 200x magnification.

Only a sample of the 1990 data are presented, namely the RT and MP treatments for the four harvests from 25 to 48 DAP, inclusive. Arbuscular colonization increased from 10% in the MP treatment at 25 DAP, to as high as 60% at 48 DAP with the RT treatment (Fig. 1a). Colonization was greater on the RT than the MP treatment at each of these sampling times, although at 32 DAP this difference was significant only at P = 0.09. Colonization of samples from the NT treatment were similar to the RT treatment, while colonization of the samples from the CP treatment was intermediate between the MP and the RT treatments (data not shown).

Shoot P concentration under the RT treatment was greater than that in the MP treatment at 32 and 39 DAP (Fig. 1b). This observation was accompanied by increase in shoot dry mass from 0.11 g shoot\(^{-1}\) under MP to 0.21 g shoot\(^{-1}\) under RT at 32 DAP. The increase in shoot P content on the RT treatment between 25 and 32 DAP was much greater than that on the MP treatment (0.71 versus 0.08 mg shoot\(^{-1}\)). This observation corresponds closely to the time period when the difference in arbuscular colonization was the greatest.

Similar findings were also made the following year. The spring of 1991 was much warmer than the previous year, and the dry mass and developmental stage of the plants were more advanced at any given time after planting. Arbuscular colonization and shoot P concentration for the first four harvests in 1991, in the MP and RT treatments, are shown in Table 1. Once again arbuscular colonization was greater in the RT compared to the MP treatment, although at 22 DAP this difference was significant only at P = 0.13. Increased colonization was accompanied by enhanced shoot P concentration at the first two harvests. The NT behaved similarly to RT in these two parameters (data not shown). The increase in shoot P content from 15 to 22 DAP was 5.5 mg shoot\(^{-1}\) in the RT, compared to only 3.7 mg shoot\(^{-1}\) in the MP treatment.

Previous studies in our laboratory have reported that shoot P concentration at the 5- to 6-leaf stage can have a significant effect on final grain yield. The data here show that tillage can have a marked effect on shoot P concentration at this stage, corresponding to 32 DAP and 22 DAP in this experiment in 1990 and 1991, respectively. The effect of tillage appears to be due to an effect on the mycorrhizae, suggesting there is a potential to influence grain yield through management of this symbiosis.

**Acknowledgements**

We are very grateful to Doug Young of Ridgetown College for his kind permission to sample the field plots. Thanks also to Ranee Pararajasingham, Lori Shepherd, Catherine Dowdell and John Lauzon for technical assistance.

### Table 1. Comparative effects of moldboard plow (MP) and ridge tillage (RT) on arbuscular colonization and shoot P concentration at harvests from 15 to 36 days after planting at Ridgetown, Ontario in 1991. Pairs of means followed by different letters (a,b) in rows are significantly different at the 5% level. n = 4.

<table>
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<th>Days after planting</th>
<th>Arbuscular colonization (%)</th>
<th>Shoot P concentration (mg g(^{-1}))</th>
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<td>36</td>
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![Graph](image-url)
Forage Quality as Affected by Weather During Field Drying for Hay

D.M. Brown, A.G. Barr and D.M. Smith

A model has been developed to simulate forage quality losses (SIMFORQ) during field drying of hay based on estimates of respiratory losses of CO\textsubscript{2}, leaching of soluble carbohydrates and protein caused by rainfall, and leaf losses caused by turning the swath (tedding). A thorough literature review revealed that additional losses of dry matter from drying forage may be caused by microbial activity. Bleaching of the forage by sunlight when the swath has to be turned several times was reported also to result in reduced intake by livestock. These latter two modes of loss were not included in the original version of the model. A preliminary method for estimating microbial-caused losses was added later. The effects of bleaching are not included. The equations that estimate plant respiration and leaf losses were obtained from published results of experiments conducted to determine these losses. The equation that estimates leaching losses was derived from results obtained in an experiment using a rainfall simulator conducted during the development of the SIMFORQ model.

Moisture status of the forage during the drying period is estimated twice-per-day, using a hay drying model that estimates water loss based on the drying potential of the atmosphere which is calculated using the modified energy budget approach. Rewetting by both rainfall and dew are assumed to occur at night.

The level of dry matter and quality (ADF, NDF and CP) of the forage at the start of the drying period are based on the stage of development at time of cutting. The levels of these quality factors at each stage of development were estimated from results of a forage crop growth curve experiment conducted in the early 1960's at Guelph and other information published in recent years. The stage of development at time of cutting is determined by accumulating degree-days above 5°C from the start of growth, as determined from a forage growth model.

Simulated output from the model has been checked using two sets of data. Forage samples were collected by CICO insurance agents from 1987 through 1991 and analyzed for moisture content and quality by Agri-Food Laboratory for the first four years and by the Agri-Service Lab. in 1991. Samples from replicated hay swaths were collected at the Elora Research Station (ERS) in 1991 and analyzed by both the Agri-Service Laboratory and in laboratories at the University of Guelph.

The 1987 and 1988 moisture content results collected by CICO personnel were used to check the hay drying model. The 1989 and 1990 quality results from CICO samples were used for the first comparisons with the output from the SIMFORQ model. The 1991 CICO and ERS data were used for the final comparisons.

The 1987 and 1988 moisture data showed that the drying model was adequate for estimating moisture loss from forage, except for drying at moisture contents below 40% (wet basis) when hay was dried too rapidly. The 1989 and 1990 quality data (ADF and CP) was so variable from sample to sample that it was impossible to assess the reliability of the
SIMFORQ estimates of change in ADF and CP between cutting and harvest. Good weather following the first and second cuttings in 1991 resulted in very little loss of quality by the harvest date, as hay was harvested within three days following cutting on some farms. Again, the large variability of measured quality at both cutting and harvest made it impossible to assess the adequacy of SIMFORQ to estimate loss in quality.

Wet, humid weather following the third cutting in August 1991 provided the best measured quality results for comparison with SIMFORQ estimates. Samples were taken twice per day on the Steen Farm at the Elora Research Station. Measured ADF and NDF showed a fairly uniform increase between cutting and harvest, as the variability among swath samples was much less than for the June 1991 samples following first cutting. We found the increase in measured ADF was about 50% more than estimated by SIMFORQ, and the measured change in NDF about 20% more than estimated. These estimated changes in quality were the result of a calculated decrease of about 20% in dry matter (Table 1), whereas a loss of 30% in DM could be expected during such a long, wet, humid drying period according to information reported in the literature. Therefore, it was concluded that microbial activity during such long drying periods may cause the additional loss in DM.

The first output from SIMFORQ, with respect to changes in crude protein content, provided greater losses than measured according to samples taken following Cut 3, 1991. This overestimation led to a change in the rate of loss of protein caused by respiration compared to other dry matter losses. It is now assumed that protein is half as vulnerable to loss as other dry matter for both respiration and leaching processes. The estimated decrease in CP with this assumption appeared to match the measured losses fairly closely.

At this point, it was concluded that losses caused by microbial activity on the forage during long drying periods needs to be included. A preliminary method for estimating these losses was introduced by changing the criteria for plant respiration and al-

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Table 1. SIMFORQ estimates of forage moisture content (MC), dry matter (DM), quality factors (NDF, ADF and CP) and modes of dry matter loss, for growth cycle 3 forage, leached, Elora Research Station, Aug. 1991.
The Effect of Rye Mulch on Soybean Yields: A Field and Modelling Study

C. Wagner Riddle and T.J. Gillespie

A rye/soybean system, where rye is planted in the fall, chemically killed and mowed in the spring, and soybeans are no-tilled through the rye mulch, was evaluated through a field and a modelling experiment. The objective of this research was to determine the optimal timing of rye killing for subsequent soybean growth.

Field experiments were conducted at a sandy soil site and a loam soil site, during 1989 and 1990. Soybeans were grown on plots with two depths of mulch on the soil surface (obtained by killing rye on two dates), and on bare soil plots. Soil water content and soil temperature were monitored throughout the two summers. Soybean plants and mulch were sampled several times and analysed for dry matter. Final soybean yields and yield components were also measured. Soil water conservation under mulch was significant for short periods early in the season during one year, but did not affect early soybean growth. Generally, soil water content between the two mulch treatments was not different. Analysis of hourly soil temperatures measured under mulch and no-mulch treatments revealed that extreme temperatures are more frequent under the bare soil condition; but, over the whole growing season, these differences were limited to a small percentage of hours. Observed yields were not significantly different between treatments.

Mulch experiments with no growing plants were also conducted at the sandy soil site during 1989 and 1990. The objective was to gain fundamental knowledge of the effect of rye mulch on the microclimate and on the change of mulch characteristics over time. Soil water content, soil, air and mulch temperature were monitored under two mulch conditions and compared to a bare soil condition. Albedo and transmittance of solar radiation of mulch elements were measured. Mulch dry matter and residue area index were evaluated. Several functions that describe the physical characteristics of the mulch and their change over time were obtained.

A rye mulch/soybean computer simulation model was constructed, using the CERES-Wheat and SOYGRO as building blocks. The objective was to allow testing of the rye cover crop's effect on soybeans during several possible weather scenarios, which did not occur during the field trial seasons. The water balance subroutine (WATBAL) used in SOYGRO was modified to include the effect of rye mulch on soil evaporation and rainfall interception. Excellent agreement between simulated and observed soil water under rye mulch was obtained. Based on the simulation results obtained, killing the rye cover crop approximately one week before soybean planting resulted in the best soybean yields under a variety of rainfall conditions, on both medium and sandy textured soils.

Manure Management for Maximum Corn Yields and Environmental Protection

J.W. Paul and E.G. Beauchamp

Manure management is important within the concept of sustainable agriculture because 1) increased manure nutrient efficiency may reduce the requirement for external inputs of nutrients, and 2) there are concerns with regard to air and water quality under existing management systems. Several manures including liquid dairy cattle, solid beef cattle and composted beef cattle manures were compared to urea fertilizer with respect to corn yield, N recovery, soil mineral N remaining after corn harvest, and potential soil N mineralization after harvest. The manures were applied in the spring and incorporated with a field cultivator within twelve hours of application.

Total nitrogen (N) in liquid dairy manure, solid beef manure and composted beef manure applied in the spring was 35, 9 and 9% as available as mineral N fertilizer, respectively, after one harvest. Nitrogen uptake by corn was more closely related to the mineral N content of the manure than to its total N content. However, only 50-60% of the mineral N in the manures was as available as N fertilizer; a significant decrease in soil mineral N content was observed during the first week after manure application. This decrease was attributed primarily to NH₃ volatilization despite incorporation with a field cultivator. The contribution of N from the organic fraction of liquid dairy and solid beef cattle manure to the available N pool was not significant, and very little contribution from the organic N fraction of composted manure was observed.

Despite the poor efficiency of manure N use by corn, soil mineral N contents after harvest were not higher after manure application than after urea fertilizer application in the spring. Soil mineral N contents after harvest in 1989 and 1990 were higher with the highest rate of urea fertilizer (150 kg N ha⁻¹) than with any of the manure treatments. Nitrogen mineralization rates after crop harvest were not significantly higher in manured soil than in fertilized soil after one manure application.

Much of the N is in the organic fraction of the beef cattle manure and compost and may be released in subsequent years. Continued annual application of these manures will result in higher N mineralization rates, thereby more of the N requirement of the corn may be met from N release from the soil organic fraction. Im-
proved soil fertility as a result of long-term annual manure applications may also increase the amount of N mineralization after corn harvest in the fall. In high fertility soils, it is imperative that a crop be growing on the soil for as much of the year as possible to take up mineralized nitrogen.

Adding $^{15}$N to the mineral N fraction of the manure underestimated N recovery by corn or mineral N remaining after corn harvest. A significant amount of the labelled N was immobilized into the soil organic matter shortly after application to the soil. The addition of $^{15}(\text{NH}_4)\text{SO}_4$ to the mineral N fraction of the manure provided information on cycling of N between the organic and mineral N pools.

**Evaluation of Compost Use on Established Kentucky Bluegrass**

*P. van der Werf, T.E. Bates and R.P. Voroney*

A two year (1990-1991) field study was conducted on established Kentucky bluegrass (*Poa pratensis*), on a Lisbon sandy loam (*Psammic Hapludalf*). Composts prepared from leaves (LC), irradiated sewage sludge (ISSC) and animal manure (AMC) were applied at 0, 10, 20, 30 and 40 t compost solids ha$^{-1}$yr$^{-1}$. Treatments received recommended amounts of N, P and K by supplementing the composts with chemical fertilizers. The 0 rate, a control, received chemical fertilizers only. The effects of the composts were evaluated by determination of clipping weights, visual ratings, depth of thatch and plant and soil macronutrients. Except for depth of thatch, which increased but requires further investigation, compost addition enhanced visual ratings of established Kentucky bluegrass and supplied a portion of the plant N, P and K requirements. Increasing rates of compost application resulted in increasing scores for all visual ratings. Plant nitrate concentrations were highest in the ISSC treatments in 1990, but not in 1991, whereas plant phosphorus concentrations were consistently highest with AMC in 1990 and 1991. Plant and soil K concentrations were consistently highest with AMC which contained high K concentrations, which may have interfered with Ca and Mg uptake as plant concentrations were lower with AMC. There were few differences in clipping weights in compost treatments compared to the control. Irradiation of sewage sludge prior to composting did not result in a compost that behaved differently than composts from unirradiated sources. Compost application can benefit established Kentucky bluegrass by enhancing visual quality and supplying a portion of N, P, and K.

**Nitrogen Budgets on the Eiora and Arkell Research Stations**

*J.W. Paul, E.G. Beauchamp and H.R. Whiteley*

Nitrogen budgets were calculated for the Eiora and Arkell Research Stations operated by the University of Guelph. The budgets were calculated for three years and included the various animal units on the station as well as the land used to provide feed for the animals.

The N balances of the Eitora and Arkell research stations indicated that only 17-20% of the imported N was exported as meat, milk or eggs. Other N balances in the literature report similar N efficiencies. The feed efficiency of the various animal units exported products ranged from 7% at the beef unit to 44% at the poultry unit. Losses of imported N from the animal units were 38% and 35% of total N inputs at the Arkell and Eiora research stations, respectively. The loss of N from the field that provided feed for the animal units was estimated to be 41% and 48% of the total N inputs at the Arkell and Eiora stations, respectively. Ammonia volatilization probably accounted for most of the N lost during the period between excretion by the animal and the time of field application. Some of the volatilized NH$_3$ was probably redeposited on the fields of the stations. Ammonia emissions are not a major concern in North America at this time, but reductions in NH$_3$ emissions can be accomplished by improvements in manure management following excretion and during field application. Because the N transformations in manure are rapid and the amount of unrecovered N is large, the possibility of NO$_3$ losses from barns and manure storages must be considered.

The average manure N application rates on the fields of the Arkell and Eiora research stations were 81-98 and 113-180 kg N ha$^{-1}$, respectively, although application rates to some fields were much higher. The amount of N applied to the fields but not recovered as crops (lost via ammonia volatilization, denitrification, leaching or present as organic N) was 41 and 48% of the total N imported to the Arkell and Eiora Research Stations, respectively. The average manure application rates fall within the recommended limits of 170 to 190 kg N ha$^{-1}$ as manure for crop production as outlined in the Agricultural Code of Practice. It is important to note that these limits are based on quantity of N voided by an animal unit and do not take ammonia losses into account. Other factors such as legume plowdown, fertilizer N ap-
plication as well as timing and distribution of manure N must be considered in assessing N management for reduced groundwater pollution. Manure application to a legume forage before it is ploughed in the fall probably results in a high risk of nitrate pollution.

This study demonstrated the importance of 1) understanding manure nitrogen transformations and losses from the time of excretion by the animal through to its long term effects on the soil and crop, and 2) understanding manure nitrogen in the context of overall nitrogen management on the farm. Nitrate leaching to groundwater has been cited as a prime consideration in manure management, but should also be seen in the context of other environmental concerns such as ammonia volatilization and NO\textsubscript{x} emissions.

The amounts of nitrate-N leaving an experimental watershed at the Elora Research Station in drainage water flow ranged from 26 to 49 kg ha\textsuperscript{-1} y\textsuperscript{-1} from 1986 to 1990. In the twelve months from March 1990 to February 1991, a very wet period, the amount was 78 kg ha\textsuperscript{-1}. Nearly all of the nitrate-N was removed in the outflow from the buried pipe system that drains this watershed. Concentrations of nitrate-N in piezometers about 1 m below the depth of buried pipes were consistently lower than concentrations in buried-pipe outflow. The concentrations of nitrate-N in the drainage water from the buried-pipe system was above the drinking water standard of 10 mg nitrate-N L\textsuperscript{-1} in all seasons except winter and early spring. There was no evidence of nitrate movement from the watertable to deeper groundwater at 15 and 25 m because of low permeability till. In this stratigraphic setting the outflow from the buried pipe system is by far the major pathway for nitrate movement from this watershed.

Efflux of Trace Greenhouse Gases from Agricultural Sites into the Atmosphere

G.W. Thurtell, E.G. Beauchamp, G.E. Kidd and K.M. King

Trace gases have gained a prominent position among scientific topics because they cause serious economic damage to agricultural crops, damage buildings, cause health problems, destroy the ozone layer, cause smog, and they are responsible for the greenhouse effect and climate change, etc. While agricultural productivity is affected in several ways by trace gases in the atmosphere, it can also be a source of some gases and a sink for others. The magnitude of these agricultural sources and sinks is not known accurately because no suitable measurement technology has been available. As a result, it is not presently possible to construct a reliable inventory database.

Previous work has shown that greenhouse and other trace gases are added to and removed from the atmosphere by natural and agricultural production systems (e.g. methane is produced by ruminants and absorbed by soils; nitrous oxide is emitted from soils). However, considerable uncertainty exists in the amounts involved and in the controlling mechanisms. Significant efforts are beginning world-wide, in many economic sectors, to obtain better information on the various greenhouse gases and on ways to reduce emissions into, or increase removal from, the atmosphere. It is vital that we become more knowledgeable about the complex effects that we have on the atmospheric environment.

Nitrous oxide flux measurements were made at the Elora Research Station from the end of July to mid October, 1991. Tests of our instruments were most successful and in some ways exceeded our expectations. The Trace Gas Analyser was very stable without significant frequency drift being detected. The electronics and computer system performed without serious problems and the instrument was sufficiently reliable that except for filling the liquid nitrogen dewar each morning and evening it could be left unattended. A measurement of the flux of N\textsubscript{2}O was made each hour with an estimated resolution of less than 1 ng m\textsuperscript{-2}s\textsuperscript{-1}.

Our 1991 measurements of N\textsubscript{2}O indicate that these fluxes into the atmosphere from bare soils are very variable. While the final analysis is not complete, typical emissions were in the range of 5 ng m\textsuperscript{-2}s\textsuperscript{-1}; but values 10 to 100 times larger occurred for periods of a few days (Fig. 1), because of irrigation or rainfall, but not consistently (Fig. 2). Application of ammonium sulphate (Fig. 3) followed by irrigation did not produce a significant increase in the flux. Application of a large source of soluble carbon (sugar) in October (Fig. 4) caused large losses of N\textsubscript{2}O and presumably nitrogen (N\textsubscript{2}) as well, through stimulation of denitrifying microbial population. It is clear that measurements, to be reliable, must be made on a continuous basis. In addition, we believe simultaneous measurements at different sites are required if meaningful comparisons are to be made.

We are now planning to measure fluxes of N\textsubscript{2}O, CH\textsubscript{4}, and CO in 1992. Either the eddy-correlation or a gradient method will be chosen in each situation to optimize the experiment.

Our instrumentation can be adapted for energy-balance, diffusion theory, or momentum balance concentration gradient measurements, thus allowing systems to be studied that do not satisfy the restrictions dictated by the eddy-correlation method. One example is the long uniform fetch requirement imposed by the physical size of sonic anemometers. Since trace gas flux measurement needs vary so widely, the option to choose the best technique for a specific application can determine the success of a research program. Our laser technology can also provide the concentration gradient data required by these methods. Because the energy balance method does not require bulky instrumentation at the point of measurement, data can be obtained in
the air only a short distance above the soil surface. This provides the capability to make accurate trace gas flux measurements from relatively small experimental plots using a non-disturbing technique. We used this method for our measurements in 1991.

The instrumentation is now capable of making these measurements in real time, on a continuous basis. For example, measurements can be made continuously for several weeks with a computer output of the average trace gas flux and concentration data for each two hour period being immediately available, in the field, allowing interaction by the researchers on the site.

The results of our 1991 measurements are currently being prepared in the form of a report and for publication.

Soil Analyses

In addition to the \( \text{N}_2\text{O} \) efflux measurements reported above, soil cores were periodically taken from the experimental area from May to November for laboratory analyses. Following gas chromatographic procedures, \( \text{N}_2\text{O} \) production by soil cores was monitored in the presence or absence of acetylene. Acetylene blocks the conversion of \( \text{N}_2\text{O} \) to \( \text{N}_2 \) by soil denitrifiers and thereby provides a measure of denitrification. In the absence of acetylene, the production of \( \text{N}_2\text{O} \) reflects the activities of nitrifiers (\( \text{NH}_4^+ \) to \( \text{NO}_3^- \) and \( \text{N}_2 \)) and denitrifiers (\( \text{NO}_3^- \) to \( \text{N}_2 \) and \( \text{N}_2\text{O} \)) in soils.

While the measurement of gases produced in soil cores as described is a typical approach in studies of this kind, only a periodic "snap shot" of the \( \text{N}_2\text{O} \) gas production is possible compared with the continuous monitoring of fluxes with the Trace Gas Analyser. Although there was some agreement between measurements by the soil core method and the Analyser, discrepancies often occurred and these require further study.

It is possible to measure \( \text{N}_2\text{O} \) produced by nitrifiers and denitrifiers as well as \( \text{N}_2 \) (with acetylene) produced by denitrifiers. At very low gas production rates, the ratio of \( \text{N}_2\text{O}/\text{N}_2 \) was very high, ranging up to 0.5 of the total N gas produced. On the other hand, at higher N gas production rates, the \( \text{N}_2\text{O}/\text{N}_2 \) ratio was usually lower than 0.1 and seemed to depend on the denitrification rate. If the conditions affecting the \( \text{N}_2\text{O}/\text{N}_2 \) ratio could be predicted, it might be possible to predict denitrification rates from \( \text{N}_2\text{O} \) flux measurements in the field.

In addition to \( \text{N}_2\text{O} \) measurements with the soil cores taken from the field, \( \text{N}_2\text{O} \) production was also monitored using fluorescence spectrometry. A small quantity of \( \text{NO} \) was produced only in May from soil in which manure was applied to alfalfa and incorporated.

Some laboratory experiments were conducted to measure \( \text{NO} \) and \( \text{N}_2\text{O} \) production in manure-treated soil. Both gases were produced in substantial quantities shortly after relatively large quantities of manure were added to soil. Further studies were done to study the stability of \( \text{NO} \) and \( \text{N}_2\text{O} \) production in laboratory systems. It was discovered that \( \text{NO} \) is partially transformed to \( \text{NO}_2 \) gas in the presence of acetylene and that another unknown product is produced.

Effects of Soil, Nature of Substrate and Substrate Addition Rate on Decomposition

Z. Zhang and R. P. Voroney

Several physical, chemical and biological factors affect the decomposition rate of organic materials in soil. However, soil ecosystems are so complex that many aspects of decomposition processes are poorly understood. The aim of this research was to investigate the effects of soil, nature of substrate and substrate addition rate on the decomposition rate.

A 3 x 3 factorial design was used. Organic materials labelled with \( ^{14}\text{C} \), including glucose, corn grain and corn stover, were added to soils including a sandy loam, loam and clay loam, at rates of 0.4, 1.6 and 3.2 mg \( ^{14}\text{C} \) g\(^{-1}\) soil. The properties of the selected soils are given in Table 1.

Soils mixed with each substrate were incubated at 25 °C. The soil water potential was controlled at -45 kPa. After 35 days of incubation, \( ^{14}\text{C} \) remaining in the soil was measured (Table 2).

Effects of soil, substrate itself and addition rate on the decomposition rate are shown in Figure 1. There was no evidence of an effect of soil texture on the decomposition rate. The fact that fine-textured soils usually contain more organic matter is probably due to greater additions of plant residues and to less leaching, compared to coarse-textured soils.

The nature of substrate significantly affected the decomposition rate (\( p<0.05 \)). The extent of decomposition in soil largely depends on the chemical structure and complexity of organic materials, and in other words, on the ease of attack and utilization by soil organisms.

The decomposition rate was also significantly affected by the addition rate (\( p<0.05 \)). The percentage of \( ^{14}\text{C} \) remaining in soil decreased with increasing addition rate. Effects of the addition rate may be explained by the rapid death of microbes due to starvation. The more microbial biomass increases initially, the greater the microbial biomass declines later. The higher rate of substrate addition results in more microbial biomass and hence, is helpful for enhancing the
decomposition rate. Another explanation could be the soil's preservation capacity, i.e. the specific capacity of the soil to preserve or protect microbes.

Table 1. Selected soil properties

<table>
<thead>
<tr>
<th>Soil textural class</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>W @45kPa</th>
<th>Org. C</th>
<th>Tot. N</th>
<th>P mg kg⁻¹</th>
<th>K mg kg⁻¹</th>
<th>Mg mg kg⁻¹</th>
<th>Ca mg kg⁻¹</th>
<th>CEC cmolc kg⁻¹</th>
<th>pH</th>
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<tr>
<td>Sandy loam</td>
<td>58</td>
<td>23</td>
<td>19</td>
<td>15.7</td>
<td>1.48</td>
<td>0.13</td>
<td>11</td>
<td>139</td>
<td>387</td>
<td>1840</td>
<td>9.6</td>
<td>6.6</td>
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<tr>
<td>Loam</td>
<td>42</td>
<td>34</td>
<td>24</td>
<td>22.0</td>
<td>1.76</td>
<td>0.14</td>
<td>18</td>
<td>134</td>
<td>411</td>
<td>1870</td>
<td>18.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Clay loam</td>
<td>21</td>
<td>39</td>
<td>40</td>
<td>27.2</td>
<td>2.11</td>
<td>0.19</td>
<td>14</td>
<td>112</td>
<td>196</td>
<td>2120</td>
<td>20.9</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 2. Decomposition rates after 35 days of the incubation

<table>
<thead>
<tr>
<th>Substrate Addition rate (mg ¹⁴C g⁻¹ soil)</th>
<th>Glucose 0.4</th>
<th>Glucose 1.6</th>
<th>Glucose 3.2</th>
<th>Corn grain 0.4</th>
<th>Corn grain 1.6</th>
<th>Corn grain 3.2</th>
<th>Corn stover 0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>41.6±0.8</td>
<td>30.9±1.7</td>
<td>26.0±1.1</td>
<td>43.0±1.8</td>
<td>38.7±0.9</td>
<td>35.9±0.6</td>
<td>59.2±1.9</td>
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<tr>
<td>Loam</td>
<td>41.2±1.3</td>
<td>30.0±16</td>
<td>26.3±0.6</td>
<td>43.0±1.8</td>
<td>40.1±1.5</td>
<td>36.2±0.9</td>
<td>59.8±1.9</td>
</tr>
<tr>
<td>Clay loam</td>
<td>41.3±1.1</td>
<td>31.5±0.8</td>
<td>26.7±1.4</td>
<td>43.3±1.1</td>
<td>38.9±1.5</td>
<td>36.6±0.8</td>
<td>60.3±1.9</td>
</tr>
</tbody>
</table>

Note: replicates=3.

Figure 1. Effects of soil, nature of substrate and substrate addition rate on the ¹⁴C remaining in soil.
Role of Collembola in Organic Matter Decomposition in Soil

Z. Zhang and R. P. Voroney

Although the effects of soil fauna on the decomposition of organic matter have been studied for many years, the mechanisms by which soil fauna regulate the decomposition processes are not well understood, especially under what conditions and by which activities these animals play their role in decomposition. In addition, the results of most previous studies were from leaf-litter systems and, hence, might not apply to systems including soil.

In this research, the role of Collembola (Isotomidae: Folsomia candida Willem) in the decomposition processes of glucose, corn grain and corn stover (Zea mays L.) were studied by following changes in CO$_2$ evolution. Several environmental situations including the presence of Collembola, sterilization of soil and placement of organic substrate were considered. The experiments were conducted on a sandy loam soil, using a tracer techniques ($^13$C-labelled organic materials) and a microcosm system.

Cumulative $^13$C-CO$_2$ evolved during the incubation is summarized in Table 1. Collembola significantly depressed or enhanced CO$_2$ evolution, depending on the microbial inoculum potential and the nature of the organic materials. Collembola was most effective in the experiments using sterilized, and then inoculated soil mixed with the organic materials, enhancing the $^13$C-CO$_2$ evolved from glucose and corn grain by 10.1% and 5.6% ($p<0.01$), respectively, but reducing the $^13$C-CO$_2$ evolved from corn stover by 16.9% ($p<0.01$), compared to controls without Collembola. In the experiments using unsterilized soil with substrates placed on the surface, Collembola increased the $^13$C-CO$_2$ evolution from the grain by 2.7% ($p<0.05$), but depressed it by 6.2% ($p<0.01$) for the stover. There were less or insignificant differences between presence and absence of Collembola in the experiments using unsterilized soil amended with the organic materials (Fig. 1).

Table 1. Cumulative $^13$C-CO$_2$ evolved during the incubation

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Glucose</th>
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<th>Corn stover</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Sterilized soil*</td>
<td>976</td>
<td>1074</td>
<td>907</td>
</tr>
<tr>
<td>Unsterilized soil (+)</td>
<td>1069</td>
<td>1079</td>
<td>868</td>
</tr>
<tr>
<td>Surface placement (7)</td>
<td>998</td>
<td>1025</td>
<td>685</td>
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</table>

*incubated for 56 days; + incubated for 35 days.

Figure 1. Effects of Collembola on the decomposition of glucose, corn grain and corn stover.
Agrogeology Projects in Ethiopia Still Going Strong

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

Despite political and security problems which shook Ethiopia in 1991, the Ethiopia-Canada agrogeology projects are still going strong. The two agrogeology projects which are carried out by staff from the Institute of Agricultural Research and the Institute of Geological Surveys in cooperation with agrogeology staff from Land Resource Science are 1) Igneous phosphate and 2) Rock mulching.

The objective of the igneous phosphate project is to make use of locally available phosphatic rocks to improve the soils of the Nejo-Ghimbi area, Wollega province, W. Ethiopia. Here, the limiting factors for increased agricultural productivity are soil acidity (soil pH between 4.4 and 4.6) and strong phosphorus deficiencies. The naturally occurring phosphates of Bikidal, some 40 km North of Chimi, were studied on their geology, mineralogy and chemistry. These studies confirmed that the phosphates are of low grade and of low solubility. It became clear that in order to increase the agronomic effectiveness of these phosphates they would require considerable upgrading and appropriate processing.

During 1991, research on practical, adapted, phosphate upgrading processes were started in the laboratories of the Ethiopian Institute of Geological Surveys. The processes used include simple disaggregation, classification and magnetic separation. The results of initial processing indicate low grade ore (5.7 - 8.8 % \( P_2O_5 \)) could be upgraded to 23 - 36 % \( P_2O_5 \) with a recovery of two additional co-products.

Greenhouse experiments using the concentrated phosphates are in progress.

The other agrogeology project, rock mulching, also made considerable progress. The soils at the trial sites at Melkassa were studied in detail and chemically analyzed. The soil problems in the Melkassa-Zway area and large parts of the rift valley are not soil fertility (the soils are very fertile), but the unpredictable and irregular rainfall leading to considerable moisture stress in the soils. In adaptation of the rock mulch farming systems of the Canary Islands, Spain, the project studied the effects of applying a thin layer of locally available pumice and scoria rocks as mulch on the moisture retention in these soils. The results of the first experiments are shown in Figures 1 and 2.

The experiments clearly demonstrate that soil moisture could be conserved considerably and that the moisture conserved by means of rock mulching increased the grain yield by up to four times the control.

The experiments will be continued on fields with corn but also with horticultural crops and fruit trees.
Land
Inventory &
Stewardship
The Natural Heritage Stewardship Program

S. Hilts

This ongoing research program reached a major turning point during 1991. Over the past eight years, landowner contact efforts have been carried out in Carolinian Canada, along the Niagara Escarpment, and among wetlands in southern Ontario. This year no new landowner contact took place. Rather, an evaluation study of the program was conducted, involving interviews with 60 landowners along the Niagara Escarpment. This work, conducted over the summer of 1991, resulted in a report to the Ontario Heritage Foundation summarizing landowners’ attitudes to the program.

Briefly, landowners support the program, specifically the Natural Heritage Stewardship Award, strongly. They also appreciate the newsletter Land Matters, produced here, and mailed to all participants. Areas where improvement is needed include providing more specific information on who to contact for help, and providing other follow-up services for landowners.

Three workshops were held in different locations, and with different topics, during the fall months. Such workshops appear to be of considerable interest, but only to a small number of landowners.

The program in the Department of Land Resource Science continued to produce the newsletter Land Matters, and also provided a week-long training program for staff of the Wetlands Habitat Agreement.

In October of 1991, funding for the major part of this program elapsed, and both Tom Mouli and Jo-Anne Rzadki left the project to pursue other careers. Tom is the Research Director for the Ontario Commission on Planning and Development, and Jo-Anne as an independent consultant. Jo-Anne will still be editing our newsletter in that capacity.

Evaluation of Land Trusts for Conservation

S. Hilts

During the agricultural land policy review described in “Evaluation of Alternate Agricultural Land Protection Policies”, it has become apparent that Agricultural Land Trusts often play a key role in the implementation of policies to conserve land in the U.S. case. As a result, a special focus has been developed on Land Trusts as a possible vehicle for policy implementation. Further research will explore the specific potential for Land Trusts in Ontario. A network of interested organizations has already been established to pursue this route, and a major workshop is planned for late March, 1992.

Information has been gathered from a number of U.S. Land Trusts which focus on agricultural land protection, and from the U.S. Land Trust Alliance. Presently, examples of such activity in Canada are being sought.
Evaluation of Alternate Agricultural Land Protection Policies

S. Hilts

A major project under the OMAP program on Agricultural Land Resources has been developed over the past year to inventory and begin evaluating the set of alternative policies that can be used to protect agricultural land. This work has been started in anticipation of being a larger focus of future work. A comprehensive literature review has been completed, along with an extensive annotated bibliography, both in the process of being finalized at present. Work has now begun on the evaluation of the implications of adopting alternative policies for the Ontario case and will be the focus of further research proposed in the new program.

The work grew not only as a research initiative in the Department of Land Resource Science, but also because of discussions held with the Land Use Planning Branch of the Ontario Ministry of Agriculture and Food, staff of which indicated an interest in developing further research in this area. Although there are many policies that may impact on the use of agricultural lands, concerns expressed by this Branch of OMAP have led to an initial focus on those policies that might be specifically directed at the preservation of agricultural land.

As well, a series of discussions have been held with representatives of a number of non-government organizations interested in the preservation of agricultural land. This loose group that called itself the 'Countryside Coalition' put together a Position Paper attempting to state clearly the need for policies which take an integrated approach to dealing with issues in the rural landscape.

Among the agricultural land preservation techniques that have been reviewed are the purchase and transfer of development rights, conservation easements, assessment and taxation policies, agricultural districts and zoning, along with comprehensive integrated programs. Much of the relevant literature comes from U.S. experience, but with the appointment of Ontario's Commission on Planning and Development, commonly known as the Sewell Commission, the results of this work take on more importance for Ontario.
Publications
Papers presented
Seminars
Titles of Books and Chapters in Books


Publications in Referred Journals


Non-Refereed Reports and Publications


Seminars and Papers Presented


Martini, I.P., Cold climate peatlands of Canada, with particular reference to the Hudson Bay Lowland, Seminar, Dept. of Geology, Rand Afrikaans University, Johannesburg, S. Africa. March 1991

Martini, I.P., Permocarboniferous coal bearing sequences of Brazil. Seminar, Dept. of Geology, Rand Afrikaans University, Johannesburg, S. Africa. March 1991


Martini, I.P., Evolution and characteristics of a cold climate peatland, the Hudson Bay Lowland, Ontario, Canada, Seminar, Department of Geology, Witwatersrand University, Johannesburg, S. Africa


Departmental Seminars


Keeney, Dennis, Leopold Centre, Iowa State Univ. Research and Educational Programmes in Sustainable Agriculture in Iowa. February 7, 1991.


### CLIMATOLOGICAL DATA AT THE ELORA RESEARCH STATION, 1991

<table>
<thead>
<tr>
<th>MONTH</th>
<th>MEAN DAILY TEMP (°C)</th>
<th>CORN HEAT UNITS</th>
<th>DEGREE DAYS &gt;5°C</th>
<th>DEGREE DAYS &lt;18°C</th>
<th>TOTAL PRECIPITATION (mm)</th>
<th>MEAN WIND SPEED (km/hr)</th>
<th>MEAN DAILY SOLAR RADIATION (MJ/m²)</th>
<th>MEAN DAILY NET RADIATION (MJ/m²)</th>
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</tr>
<tr>
<td>Diff.</td>
<td>1.1</td>
<td>1</td>
<td>22.5</td>
<td>-34.9</td>
<td>20.5</td>
<td>2.8</td>
<td>1.3</td>
<td>0.1</td>
</tr>
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<td>NOV.</td>
<td>1.1</td>
<td>18.2</td>
<td>506.7</td>
<td>56.1</td>
<td>19.4</td>
<td>5.1</td>
<td>0.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Diff.</td>
<td>0.8</td>
<td>26.8</td>
<td>-9.6</td>
<td>2.9</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>DEC.</td>
<td>-4.0</td>
<td>1.6</td>
<td>681.7</td>
<td>56.8</td>
<td>19.9</td>
<td>5.1</td>
<td>-0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Diff.</td>
<td>1.2</td>
<td>-0.7</td>
<td>-36.2</td>
<td>-14.7</td>
<td>2.3</td>
<td>0.9</td>
<td>0.0</td>
<td>0.0</td>
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<td>YEAR</td>
<td>6.7</td>
<td>2941</td>
<td>2123.5</td>
<td>4123.4</td>
<td>888.3</td>
<td>175.4</td>
<td>63.9</td>
<td>7.3</td>
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<tr>
<td>Diff.</td>
<td>0.7</td>
<td>341</td>
<td>211.8</td>
<td>-396.4</td>
<td>52.4</td>
<td>17.4</td>
<td>7.3</td>
<td>6.9</td>
</tr>
</tbody>
</table>

M = DATA MISSING

"Diff." equals this year's value minus the 1951-1980 normal value.