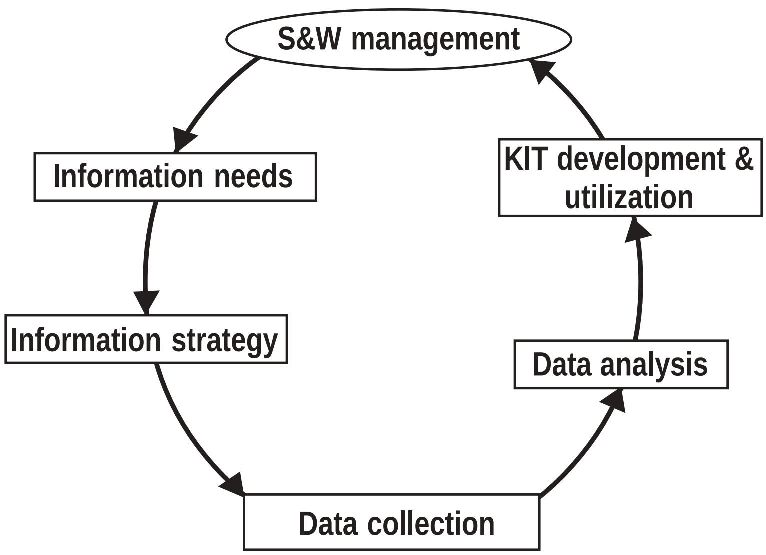
SWMnet Discussion Paper No. 2

System Databases and Simulation Models as Tools for Soil and Water Management in ECA:
Towards Increased Research Efficiency and Impact

Report on a Regional Workshop
held at
ICRAF Campus, Nairobi, 28-30 October 2002



***Edited by*:**
N Hatibu and KPC Rao

Sponsors

NRSP-DFID	DFID Natural Resources Systems Program
SWMRG-SUA	Soil-Water Management Research Group – Sokoine University of Agriculture
OSWU	Optimizing Soil Water Use
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics

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Contents

Acronyms

AEZ	Agro-Ecological Zones
APSIM	Agricultural Production systems SIMulator
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
DFID	Department for International Development of the Government of UK
DSS	Decision Support Systems
DSSAT	Decision Support System for Agrotechnology Transfer
ECA	East and Central Africa subregion comprising countries that are members of ASARECA (Burundi, DR Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda)
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IT	Information Technology
KIT	Knowledge, Information and Technology
NARS	National Agricultural Research Systems
NRM	Natural Resource Management
NRSP	Natural Resources Systems Programme of DFID
OSWU	Optimizing Soil Water Use Consortium
PARCHED-THIRST	Predicting Arable Resource Capture in Hostile Environments During The Harvesting of Incident Rainfall in Semi-Arid Tropics
S&WM	Soil and Water Management
SUA	Sokoine University of Agriculture
SWMnet	Soil and Water Management Research Network of ASARECA
SWMRG	Soil-Water Management Research Group (located at SUA but includes researchers from several organizations in Tanzania)
WSSD	World Summit on Sustainable Development

Preface and Acknowledgements

The workshop was truly participatory and this report is designed to reflect the mutual consensus reached by the participants. The excellent presentations made at the workshop have not been presented in full, since they were comprehensively discussed – only the results of these discussions are presented in this report. The workshop participants agreed that innovative application of information technology (IT) tools such as databases and modeling will produce knowledge that can be shared across sites, eco-zones and countries. This will contribute to improving the efficiency and measurable impact of research in soil and water management in the subregion. The most important result of the workshop was the articulation of what requires to be done to achieve greater use of IT tools. Furthermore, the participants called for further prioritization of the identified interventions so as to design the most effective strategy for the region. It is for this reason that this report has been published as a discussion paper. The main part of the report will also be produced in French to facilitate discussion in Madagascar, Burundi, Rwanda and DR Congo.

Several individuals and organizations, in various ways, made the workshop possible. We would like to acknowledge the contributions of the following:

- Members of the Interim Regional Steering Committee of SWMnet in all the ten member countries of ASARECA, for their diligent efforts to identify good country representatives. We regret that the representative of one country could not participate despite efforts by the SWMnet representative to facilitate this.
- The Natural Resources Systems Programme (NRSP) of DFID for supporting the bulk of the cost of the workshop through its financing of project R8088 at the Soil-Water Management Research Group (SWMRG) of the Sokoine University of Agriculture, Tanzania.
- The management and staff of SWMRG, for providing the secretariat support to the workshop, and preparation of this report. Despite little past experience, the administrative staff made all the travel and logistical arrangements to bring the participants to Nairobi from all corners of ECA. For this we say thank you very much.
- ICRISAT for providing funds, management and administration and all logistical support for workshop implementation at the ICRAF campus in Nairobi. The attendance of several of its staff at the workshop was suported by ICRISAT, as well as the final layout and printing of this report.
- The Optimal Soil-Water Use Consortium (OSWU), for financing the attendance of several participants at the workshop and also for meeting the cost of printing this report in both English and French.
- The World Agroforestry Centre (ICRAF) provided a most conducive atmosphere for the conference and supported the attendance of three of its scientists.
- Last, but most important, the dedication and hard work of the participants helped make the workshop a success. We acknowledge the contribution of each individual participant and their organizations for the time input in terms of the preparation of papers as well as attending the workshop. We are aware that if put in monetary terms, their aggregate contribution was perhaps the largest component of the workshop sponsorship.

1 Introduction

1.1 Background and rationale

The World Summit on Sustainable Development (WSSD) held in 2002 resolved to focus development efforts on five major areas, in short ***WEHAB***, meaning:

- **W**ater and sanitation,
- **E**nergy,
- **H**ealth and environment,
- **A**griculture, and
- **B**iodiversity

The framework for action on water and sanitation states that '***in countries seriously affected by drought, land degradation, desertification or floods ... the poor are the most vulnerable ... since they rely essentially on land and water resources to sustain their livelihood. Water affects almost all other sectors of the economy, and could potentially become a binding constraint on economic growth***'. One of the activities identified for overcoming this constraint is to develop national information management and monitoring programs. This will require an increased development and effective utilisation of databases. On the other hand, the framework for action on agriculture emphasizes sustainable improvement of agricultural productivity while conserving biodiversity, soil fertility and efficiency of water use. Several actions that are related to soil and water management (S&WM) have been recommended. These include:

- Scaling up of proven technologies to arrest land degradation and improve soil fertility and water management and use practices, starting by
- Taking stock of knowledge and experience existing at the local, national and international levels, in a more systematic and detailed manner, including
- Establishing information mapping, sharing and exchange systems, encouraging co-operative and partnership efforts at all levels, and building the capacity for developing and using information systems.

Therefore, soil and water resources management in general, and in particular handling of related information, are critical to the successful implementation of WSSD objectives in the region. This means that there is a need to improve the provision of information and knowledge base for decision-making. It is well understood that decision-making and planning in natural resources management (NRM) require a lot of data and information because of the long-term nature of processes and results of any action. Yet, in the region and perhaps the whole of sub-Saharan Africa, even the little amount of data and experiences that are being generated within research and development programs are inefficiently managed and hardly used. The main reason for this state of affairs is insufficient data handling and synthesis into useful knowledge and advice. This is in turn caused by a failure to adopt the modern techniques for data management that have been made possible by recent advances in IT. The regional workshop reported here was therefore organised to take an in-depth stock of the situation from both national and international perspectives.

The Soil and Water Management Research Network (SWMnet) is one of the ASARECA networks, with a mandate for promoting and strengthening research in NRM. The aim of SWMnet is to *promote sustainable and optimal utilization and conservation of soil and water resources in east and central Africa (ECA).* One of the outputs designed to contribute to this purpose is stated as *enhanced and increased availability of appropriate S&WM technological packages in ECA*. This will be delivered through several activities that include:

- Identification, evaluation and dissemination of existing S&WM technologies, practices and innovations.
- Development of tools for assessing the costs and benefits of S&WM technologies in relation to rural livelihoods, agricultural production and environment.
- Development of viable tools for dissemination and enhancing adoption of technological packages for a range of potential users.

Furthermore, since its inception SWMnet has been designed to focus more on transfer of available technologies. The NRM strategy of ASARECA requires SWMnet to:

- Harness and benefit from collaborative work of key NRM scientists, especially from the universities in the region,
- Concentrate on the compilation and dissemination of results of past research, and strengthen communication and collaboration among scientists, and
- Facilitate soil and water research to become the backbone of NRM research in the region.

This strategy requires the use of strong modern IT-based tools. On the other hand, the overall strategy of ASARECA also emphasizes enhancement of information exchange among participating partners. It is stated that this will require the ASARECA networks to develop and promote regional and national information exchange systems, such that at least 10 relevant and accessible electronic databases will be established and made available by 2007, and networks will continue to update the databases and their use to accelerate technology uptake.

It is against this background that the workshop was organized. The purpose was to evaluate the availability of databases and models for S&WM that can be used to enable SWMnet to play its role of increasing the availability and utilization of appropriate knowledge, information and technological (KIT) options for S&WM in ECA.

A brief description of the role of databases and system simulation models is given in the following sections.

1.2 Databases

A database is a system for organizing, storing, adapting and retrieving information and data. Many international and national organisations in developed countries already have and are continuing to develop a multitude of databases. However, the participation of the ECA region in the development and use of these or similar databases has been minimal. For this reason, most of the global databases are not robust enough to use for decision-making at a local level. At the same time, a vast amount of experience, knowledge and even technologies for S&WM already exists in the region. An example is the experience with irrigation found in the Sudan and how it could be used to guide planning in other countries. It is through the construction of appropriate databases and providing access to them that the existing knowledge and experiences can be organized and made available for use across the region.

1.3 System simulation models

System simulation models provide a framework that allows quantitative assessment of various biophysical processes operating in the complex agricultural systems in an integrated way. They also serve as important tools to test alternative hypotheses, planning and management of various strategies, and evaluation of their long-term impacts on productivity and sustainability. Models are also very useful in spatial and temporal extrapolation of experimental results. The use of simulation models, which so far has been confined to research, is fast expanding to address real world problems, more so with the increased emphasis on improvement in livelihoods, integrated approaches in NRM research, and related development strategies. Some areas where the benefits of simulation are well demonstrated include optimization of fertilizer management, management of climate-related risks, adding value to seasonal climate forecasts, irrigation scheduling and land use planning.

In recent years several models such as APSIM, DSSAT and PARCHED THIRST have been developed or introduced in the region. However, these have not been widely applied. The main reason may be that the critical constraints facing potential users have not been well articulated and/ or attended to. One aim of the workshop was therefore to initiate a process of articulating users' constraints.

1.4 Objectives of the workshop

Goal: To enhance the exchange of information, knowledge, technologies and experiences on S&WM so as to increase the impact of S&WM research in ECA

Purpose: To identify opportunities and constraints for the use of system database and simulation models as planning and management tools for S&WM in ECA and suggest elements for a regional strategy

Outputs:

i) The current status in the development and use of databases and models for S&WM in the ECA region – described

ii) Challenges and opportunities for application of the simulation models to S&WM problems – compiled

iii) Challenges and opportunities for data availability and database development – described

iv) Elements of a strategy for SWMnet with regard to development of databases and use of simulation models for enhancing research impact through exchange of information and technology – proposed

1.5 The workshop process

Twenty-four participants, together representing nine out of the ten countries that are members of ASARECA and three CGIAR centers (ICRISAT, ICRAF and CIAT), attended the workshop. There were also one participant from South Africa and one from USA. The list of participants is given in Annex 1. The workshop was implemented through an intensive work schedule over a period of two and a half days. The opening session was used to hear the perspectives of the organizers and sponsoring institutions. In his remarks, the ICRISAT Regional Representative for East Africa pointed

out that *ICRISAT has been one of the leading research organisations in the field of crop simulation modeling since 1982*. ICRISAT's work in this area has demonstrated that models can be useful in assisting decisions even at farm level. The coordinator of NRM research supported by DFID in East Africa emphasized the need to focus on knowledge sharing and technology uptake. The representative of SWMRG reiterated the workshop rationale by pointing out that currently many useful research results are wasted due to inadequate handling and packaging for sharing.

All the nine country representatives presented reports that covered the following issues:

- Type of models and Decision Support Systems (DSS) for S&WM known to have been used or developed in the country.
- Current known research projects in the country that are developing models or components of models.
- Constraints to model development and use in the country.
- Existing databases, their accessibility and use for S&WM in the country.
- Currently known types and uses of databases in the country.
- Identified constraints to development and use of databases and models in the country.
- Suggestions about future opportunities, needs and the way forward.

The main issues raised by each of the country papers are summarized in Annex 2. Six issues papers were presented at the workshop and are summarized in Annex 3.

After the presentations, the participants conducted logical analysis in both plenary and group sessions. In the first round, two groups were formed to synthesize the current status, on the basis of the country and issues papers. The groups also received demonstrations and undertook hands-on testing of a few models as a practical way of assessing the current situation. This was followed by identification of challenges and opportunities for improving the current status in relation to the use of databases and models. Outputs from groups were presented at a plenary session, which then identified four main areas that were considered to require priority attention to remove binding constraints. Then, four groups were formed to undertake a more detailed logical analysis of these four problem areas. This resulted in elements of a regional strategy, which are presented in the next section.

2 Results

2.1 Current status

Following the presentation of country and issues papers and discussions in plenary and group sessions, it was agreed that the current status could be described as summarized in the following subsections.

2.1.1 Modeling

i) There are perhaps too many models being used in the region, although the countries of ECA are at varying levels in terms of the extent of development and application of models. At the same time, most models are still under development or testing, and are therefore only used to a limited extent and mostly in academic institutions.

ii) Only very few models are used across several countries in the region, or even across several institutions in the same country. This is perhaps because most models are empirical and therefore site-specific and there is not much coordination within and across countries in the development and utilization of the models. Furthermore, most of the available models deal mainly with biophysical aspects, with only limited linkages to livelihood outcomes. This is perhaps the reason why there is little in terms of demonstrated role of models in improving impact of S&WM research.

iii) A serious limitation is that the development or use of models is often not institutionalized – it depends on individual enthusiasm with limited institutional support. There are several examples of modeling efforts that stopped after the retirement of the senior scientist who was promoting the efforts. For this reason, in nearly all countries in the region, expertise in modeling is very limited.

2.1.2 Databases

i) In most cases, there is no organized, standardized, coordinated and quality-assured system for database development and updating, mainly because there are too many uncoordinated organizations collecting similar data. Furthermore, even within individual organizations there are only limited efforts towards the development and maintenance of databases. This is perhaps due to shortage of expertise.

ii) Most databases are in raw format (e.g. field notes, record sheets) and are often incomplete. Therefore, users other than those collecting the information have limited accessibility to data. Furthermore, there is deliberate resistance to making datasets freely available, mainly due to cost recovery issues and concerns about intellectual property rights.

iii) More serious, original data is often not updated. Rather, there is too much recycling of especially the semi-processed outputs. Worse, often the original dataset is not kept after reports or papers have been produced.

iv) Incompatibility between models and datasets is another limitation that reduces the capability to quickly process datasets for use.

2.2 Opportunities and challenges

The workshop identified the opportunities that can be exploited to improve the use of IT tools in the management of soil and water resources in the region. These, together with the challenges facing the subregion, are summarized in the following subsections.

2.2.1 Opportunities

i) The existence of large numbers of regularly collected datasets and the availability of models offer potential for facilitating greater utilization and impact of previous and ongoing research or development projects in S&WM.

ii) At the same time, there is a renewed and increasing recognition of the role of databases and models. One example of this is the emerging demands from planners and farmers for risk analysis.

iii) The vast human resources existing in universities in the form of research students and staff have not been tapped.

iv) The current promotion of regional networking through the formation of, for example, SWMnet, represents an opportunity and rationale for promotion and adoption of IT tools in S&WM research in the region.

2.2.2 Challenges

i) Quality of data

Ensuring acceptable quality of data that goes into the databases, or for use with models, is a major challenge that must be overcome for the IT strategy to become beneficial.

ii) Institutional support

There is an urgent need for increased institutional support (at national, regional and global levels) for modeling and databases systems in S&WM. This will require:

- A convincing demonstration of the role that databases and modeling can play in improving impact of investments in S&WM,
- Establishing a more complete picture of the status of modeling and databases for S&WM, followed by prioritization of needs of the different countries, and
- Improving the capacity of a critical mass of users to demand, interpret and use outputs from models.

iii) Human capacity

The limitations in human capacity require urgent attention and improvement while ensuring effective utilization. Two challenges were identified; namely

- Mainstreaming modeling into university courses, and
- Improving the coordination of efforts within and across countries.

2.3 Elements of a strategy for East and Central Africa

The workshop proposed the following objectives for a strategy to be pursued for an increased and beneficial use of databases and models for S&WM in the sub region

Purpose: To put into operation an effective regional coordinating mechanism for application of database and modeling approaches to S&WM.

Outputs:

i) Capacity in ECA to develop and use databases and models – increased and maintained

ii) Commitment and support of stakeholders – obtained and maintained

iii) Willingness of relevant organisations and individuals to share data – increased and maintained

iv) Effective, validated and evaluated models and databases – readily available

Activities:

1.1 Design and implement short-term professional development training of relevant groups

1.2 Mainstream databases and models into formal (college and university) training

1.3 Develop and utilize appropriate IT facilities at NARS level

1.4 Build institutional capacity to support databases and modeling

2.1 Adopt and use participatory approaches in planning and evaluation

2.2 Define clearly the roles and responsibilities of the different stakeholders

2.3 Create awareness about the need for and benefits of using databases and models in S&WM

2.4 Implement an effective communications strategy

3.1 Increase awareness of value-addition that comes from sharing data and information

3.2 Establish and put into operation a system for recognizing sources and contribution of datasets – this could include mechanisms for referred publication of data and data quality protocols

3.3 Obtain agreement among stakeholders on an effective mechanism for recovering costs of data collection and communication

4.1 Establish and regularly update an inventory of existing and relevant models and databases from global, regional and national sources

4.2 Select and adapt databases and models to regional wide issues and needs

4.3 Organize and standardize approaches to handling of datasets

4.4 Ensure active participation of stakeholders in development and evaluation

4.5 Identify relevant regional and national datasets needed for validation processes

4.6 Introduce and operate anchor sites at field levels, for development and validation

2.4 Evaluation of the workshop

The participants' evaluation of the workshop was very positive and they appreciated the excellent coordination and focus on workshop objectives, which helped reach consensus. The organization was said to have provided an atmosphere for teasing out ideas, optimum interaction of participants, constructive attitudes, good participation by all during discussions, and learning from each other. The active participation in the brainstorming sessions and hands-on exercises was said to have made the workshop an extremely interactive and informative experience.

The participants were, however, concerned that:

- The time allocated for presentation was too short,
- The invitations reached them too close to the workshop dates and thus preparation time was short,
- The hands-on work with the models was insufficient, and
- The absence of social-economist experts among the participants perpetuated the biophysical focus.

3 Conclusions and the Way Forward

The main conclusion of the workshop was that databases and simulation models form part of tools essential for sustainable management of soil and water resources. If properly and innovatively applied, these IT tools can facilitate sharing of knowledge across sites, eco zones and countries. They provide a good means for understanding better the complex processes involved in the use, management (good or poor), and the degradation or conservation of resources, thus enabling the design of sound management interventions.

However, the participants agreed that the list of activities identified in the proposed strategy was too long. It was concluded that there is a need to identify and prioritize key entry points. Therefore, a task force of four people was selected to undertake the prioritization exercise and produce a Plan of Action for consideration by the Regional Stakeholders Workshop of SWMnet. The members of the task force are:

Dr Anthony Kilewe – Chairperson of the SWMnet Interim Regional Steering Committee

Prof Nuhu Hatibu – Interim Coordinator, SWMnet

Dr KPC Rao – ICRISAT

Dr Peter Muraya – World Agroforestry Centre

Annex 1: Program and List of Participants

Program

The entire program was chaired and facilitated by Dr. Anthony Kilewe.

Day 1: Monday 28 October 2002

Session 1: Opening

0830 – 0835: Remarks – Anthony Kilewe

0835 – 0840: Remarks – DFID NRM-EA – Dan Kisauzi

0840 – 0845: Remarks – SWMRG-SUA

0845 – 0850: Remarks – IWMI

0850 – 0855: Remarks – ICRISAT

Session 2: Global, Regional and Country Situation Analysis of Databases and Modeling in S&WM

0900 – 0915: Overview of major issues – Nuhu Hatibu

0915 – 0930: Burundi

0930 – 0945: DR Congo

0945 – 1000: Eritrea

1000 – 1015: Ethiopia

1015 – 1030: Kenya

1030 – 1100: Break

1100 – 1115: Madagascar

1115 – 1130: Rwanda

1130 – 1145: Sudan

1145 – 1200: Tanzania

1200 – 1215: Uganda

1215 – 1245: Discussion and formation of groups

1300 – 1400: Lunch

Session 3: Simulation Models as Tools for Research and Development

1400 – 1430: Soil-water management – Filbert Rwehumbiza

1430 – 1500: Plant nutrients management – John Dimes

1500 – 1530: Climate variability management – KPC Rao

1530 – 1600: Beyond biophysical models: Scaling-up and role of GIS – E Soini & A Awiti

1600 – 1630: Break

1630 – 1700: Distributed watershed modeling within a GIS – Tammo Steinhuis

1700 – 1730: General discussion

Day 2: Tuesday 29 October 2002

Session 4: Group Work on Situation Analysis

0830 – 1000: Group work

1000 – 1100: Group reports and consensus on main opportunities and constraints

Session 5: Case Study Work with Models and Databases Developed/used in the Region

1100 – 1300: Group Work: Hands-on evaluation of various models and databases including PARCHED THIRST, APSIM and INFOCROP

1300 – 1400: Lunch

1400 – 1530: Session 5 continued

1530 – 1600: Break

Session 6: Feedback on Case Study

1600 – 1700: Group reports

Day 3: Wednesday 30 October 2002

Session 7: Data Requirements and Database Development

0830 – 0910: Overview of issues (needs, opportunities and constraints) – Peter Muraya

0910 – 1030: Group work

1030 – 1100: Break

1100 – 1130: Group reports

Session 8: Regional Strategy for Development, Access and Use of Databases and Models in S&WM

1130 – 1300: Major element of a regional strategy – brainstorming in plenary

1300 – 1400: Lunch

1400 – 1500: Group work: the way forward

1500 – 1530: Group reports and plenary discussion

1500 – 1600: Closing

Participants

1. Awiti, Alex O
GIS Analyst
ICRAF
PO Box 30677
Nairobi, Kenya
Tel: 254-2-524126
Fax: 254-2-524001
Email: aawiti@cgiar.org

2. Delve, Robert
Senior Research Fellow
Tropical Soil Biology & Fertility Inst. of CIAT
PO Box 6247
Kampala, Uganda
Tel: 256-41-566415
Fax: 256-41-567635
Email: r.delve@cgiar.org

3. Dimes, John
Systems Modeler
ICRISAT-Bulawayo
PO Box 776
Bulawayo, Zimbabwe
Tel: 263-083-8311 to 8318
Fax: 263-083-8253/8307
Email: j.dimes@cgiar.org
jpdimes@yahoo.com

4. El Mobarak, A Magid Ali
Assistant Professor
Land & Water Res Centre, ARC
PO Box 388, Wad Medani
Sudan
Tel: 249-511-43035 (Office)
249-511-49797 (Home)
Fax: 249-511-43213
Email: melmobarak@yahoo.com

5. Hatibu, Nuhu
Associate Professor–SUA
Interim Coordinator–SWMnet
Soil Water Management Res. Group
Sokoine University of Agriculture
Tel: 255-23-260-1206
Fax: 255-23-260-4649
Email: nhatibu@suanet.ac.tz
nuhuhatibu@yahoo.co.uk
Website: www.giant.suanet/swmrg

6. Kilewe, Anthony M
Interim Chairman/SWMnet
KARI
PO Box 2140
Machakos, Kenya
Tel: 254 0733-827785
254-145-20609
254-0722-832 809
Email: kilewe@yahoo.com

7. Kinyangi, James
Research Assistant
TSBF-CIAT
PO Box 30677
Nairobi, Kenya
Tel: 254-2-524755
Email: J.Kinyangi@cgiar.org

8. Kinyua, Wamae
Biometrician
Kenya Agricultural Research Institute
PO Box 14733
Nairobi, Kenya
Tel: 254-2-4444029/31/32
254- 0722781002
Fax: 254-2-4444144
Email: kdwamae@kari.org

9. Kisauzi, Dan
DFID East Africa
Natural Resources Research Coordinating Office
PO Box 22130
Plot 29A
Kanjoka St. Kampala, Uganda
Tel: 00 256 (0)77408 593
Fax: 00 256 (0)41 530696
Email: dfidnr@nida.or.ug

10. Mbarushimana, Kagabo Desiré
ISAR-Rwanda
Institut des Sciences Agronomiques du Rwanda
B.P: 138 Butare, Rwanda
Tel: 250-530-145
Fax: 250-530-145
Email: desireka@hotmail.com

11. Mubiru, Drake N
Research Officer
Kawanda Agricultural Research Institute
PO Box 7065
Kampala, Uganda
Tel: 256-41-567696 (077-534247)
Email: mubirubazo@hotmail.com
landuse@infocom.co.ug

12. Muraya, Peter
Associate Scientist–Computer Application
ICRAF
PO Box 30677
Nairobi, Kenya

Tel: 254-2-524001
Fax: 254-2-524001
Email: p.muraya@cgiar.org

13. Mushambanyi, Munyuli Bin
Research Scientist
National Centre for Research in Natural Sciences (CRSN-LWIRO),
D.S. Bukavu, Kivu,
Democratic Republic of Congo
Tel: (256) 077579267
Email: munyuli@yahoo.co.uk

14. Mzirai, Omari B
Research Associate (PhD Student)
SWMRG – Sokoine University of Agriculture
PO Box 3003
Morogoro, Tanzania
Tel: 255-(0) 23-2601206
Fax: 255-(0) 23-2604649
Email: imzirai@yahoo.com
www: o.b.mzirai@ncl.ac.uk

15. Ntiburumusi,Ferdinand
Institute of Agronomic Sciences of Burundi (ISABU)
B.P. 795 Bujumbura
Burundi
Tel: 257 22-2565
Fax: 257-22-5798
Email: vubi2000@yahoo.fr

16. Rao, KPC
ICRISAT/ICRAF
PO Box 39063
Nairobi, Kenya
Tel: 254-2-524192
Fax: 254-2-524001
Email: k.p.rao@cgiar.org

17. Rarojoson, Ndrianja Jemisa
Chemist
Madagascar Laboratoire de Pèdologie-FOFIFA
Tel: 261-33-1166487

18. Rwehumbiza, Filbert BR
Associate Professor
Sokoine University of Agriculture
PO Box 3008 Morogoro, Tanzania
Tel: 255-23-2601206/2600798
Email: rmbiza@giant.suanet.ac.tz
rwehumbizaf2002@yahoo.co.uk

19. Soini, Eija
Ms. Geographer, GIS Coordinator
ICRAF/World Agroforestry Centre
PO Box 30677
Nairobi, Kenya
Tel: 254-2-524000
Fax: 254-2-524001
Email: e.soini@cgiar.org
www.worldagroforestrycentre.org

20. Steenhuis, Tammo S
Cornell University
Department of Biological & Environmental Engineering
Riley Robb Hall Cornell University
Ithaca NY 14853, USA
Tel: 607-255-2489
Fax: 607-255-4080
Email: tss1@cornell.edu
www.cornell.edu

21. Tesfai, Mehreteab
Assistant Professor
University of Asmara
College of Agriculture
Dept. of Land Resources & Env.
P O Box 1220, Asmara, Eritrea
Tel: 291-1-162607
Fax: 291-1-162236
Email: mehretab@caas.uoa.edu.er
mehreteabt@yahoo.com

22. Tumbo, Siza D
Lecturer
Sokoine University of Agriculture
PO Box 3003
Morogoro, Tanzania
Tel: 255-23-260-1206
Fax: 255-23-260-4649
Email: sdt116@yahoo.com
sdt116@suanet.ac.tz

23. Van Rensburg, LD
RSA
ARC-ISCW Representative IWMI
P/B X 01
Glen Bloemfontein
RSA
Tel: 27-051-8611151
Fax: 27-051-4511245
Email: debruint@glen.agric.za

24. Wafula, Benson M
Agroclimatologist
KARI, Katumani
PO Box 1230
Machakos, Kenya
Tel: 254-145-21122
Fax: 254-145-21122
Email: bwafula@icipe.org

Annex 2: Summaries of Country Papers

A. Introduction

Although the application of systems approaches in agricultural research is a recent development, significant progress has already been made in the development and use of simulation models and DSS over the past two decades. However, the progress to date in several countries in the ECA region is very limited. Much of the work done in the region is often a result of studies with external support and is confined to characterizing the production systems, agroecological zonation, water budgeting, and assessing the production potential. A major constraint to extensive use of models is the lack of availability of required data. Many models require reliable, good-quality data, and availability access to such datasets is limited. The country papers summarized here describe some of the models and databases available in the region and give an account of their use in S&WM research.

B. Country papers

BURUNDI

Ferdinand Ntiburumusi

1. Introduction

Burundi is one of the poorest countries not only in the ECA region but also in the world. According to the 2002 Human Development Report of UNDP, Burundi with a rank of 171 out of the possible 173, is the third lowest in the overall human development index. The uncertain political situation dominated by nine years of war did not allow the government to develop and implement the socioeconomic programs necessary to improve the economic well being of the people. Also neglected is the infrastructure development including research institutions. Consequently, the capacity of the country to research and develop technologies required to improve the productivity and profitability of agriculture, the main means of livelihood for more than 80% of Burundians, remained underdeveloped. Research activities in the domain of S&WM are very preliminary and development of databases and use of simulation models is nonexistent.

2. System modeling and decision support systems

In the Agricultural Research System there is a high and increasing recognition by researchers and decision-makers that a systems approach using dynamic simulation models would be useful in making recommendations to farmers by extrapolating the results from site-specific field experiments conducted at the research stations. The recommendations involving strategies for more efficient production, improved risk management, and more sustainable production systems can be improved by integrating the information generated on the crop responses to soil management, and genetic or environmental factors with information about the local soil and climatic conditions.

A review of research done at various scientific institutions in Burundi (Table 1) shows that only one model, MAGICC Scengen, was developed to simulate the effect of greenhouse gases emitted from burning fossil fuels, agriculture, industry, wastes and others. No simulation model or DSS has ever been developed for agricultural purposes like evaluating the soil, water and nutrient resources and

their management, crop growth, land resources assessment and use planning, policy analysis, and others in the country.

Table 1. Inventory of models and DSS developed or used in Burundi.

Name of institution visited	Type of model and DSS
University of Burundi	MAGICC Scengen
University of Ngozi	-
High Agricultural Institute	-
ISABU	-
Ministry of Environment	MAGICC Scengen (FAO Environment)
NGOs & Projects	Not known

3. Databases

Multiple datasets for climatic parameters such as temperature, precipitation, and relative humidity exist in many publications but are not available in digital form. Databases on hydrology, soil characterisation, soil erosion, S&WM, watershed management, soil fertility and others are not available. These databases were never compiled and stored in a systematic format for use in research and planning. However, soil and land use maps are available.

DR CONGO

Théodore Munyuli BM

1. Introduction

This paper presents the current information about the availability, access and use of database and modeling tools in the design and implementation of S&WM research and/or development programs in DR Congo.

2. System modeling and decision support systems

Modeling work in DR Congo is not very well developed. Some initiatives include the collaboration with international organizations (FAO, UNEP, UNDP, CGIAR institutions) and the technicians of the Ministry of Environment to develop decision support tools by integrating biophysical and socioeconomic models. However, their progress is adversely affected by the ongoing war. The UNDP/University of Kinshasa National biomass and forest resources project, in which components for typical Environmental/Natural Resources Information Decision Support Systems (EIDSS) are being developed, was recently initiated. Another study of significance is an ongoing project involving National Research institutes (Institut National pour l' Etude et la Recherche Agronomiques (INERA-RDC); Institut Congolais pour la Conservation de la Nature (ICCN); Centre National de Recherche en Sciences Naturelles (CRSN-Lwiro); Institut des Jardins Zoologiques et Botaniques du Congo – Kinshasa; Center de Recherche en Ecologie et Foresterie, Mabali-Equateur; Man and Biosphère (MAB) – Kinshasa; Institut Géographique du Congo (IGCO) – Kinshasa Gombe) and NGOs/GTZ aimed at developing what is called the structural village ecosystem modeling approach. The projects *Management Kongo Development Association*, based at Brussels/Catholic University of Leuven, Belgium and *Ecole régionale d'amenagement des forest tropicales* (ERAIFT) based at the University of Kinshasa with financial support from UNESCO/NDP/World Bank, also involve modeling components.Past work using different simulation models is summarized below.

Mathematical/statistical: Multiple regressions and correlations between crop/cropping systems variables and climatic variables are used in DR Congo to explore the extent to which elements of weather are responsible for fluctuations in yield.

Revised FAO Penman-Monteith equation (1990): This model allows the determining of the optimum periods for sowing by evaluating the crop water needs in relation to the rainfall distribution.

Water balance model: Water balance studies were conducted in order to help determine the effective length of growing seasons.

DSS tools: Several DSS tools were used to assess the land capability and prepare land use plans. Based on this assessment DR Congo is divided into five regions: Eastern mountain areas, Highlands of Katanga, Kasai Kwango-Kwilu-Savanna, Central Congo Basin (forest areas) and Atlantic Ocean zone

Land quality indicators: Land quality indicators were developed by integrating soil data with other biophysical information such as climate, geology and land use.

Modeling systems for C, N, and P nutrient cycles: It was planned to do this by setting up and monitoring long-term field experiments at several sites.

DSS for soil conservation in mountain areas: Efforts are on to assess the erosion hazard with Universal Soil Loss Equation in GIS environment.

TAW model: The TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and rooting depth.

Water resources management models: In DR Congo, catchment models were developed and used to simulate the runoff from catchments. For example, in Kinshasa, hydrological models are used to predict/forecast floods in the Congo basin. Developed by civil engineers of water resources division primarily for the protection of Inga Dam, the models have also been tried for agricultural purposes.

Crop growth models: Crop simulation models are used in DR Congo to predict the performance of genotypes under different environments and to characterize the environments for use in the genotype improvement programs. There are several crop growth models that simulate the growth of all annual crops based on soil and climatic conditions.

3. Databases

i. Climate. Meteorological data is collected at several research stations/institutes/University of DR Congo and is stored at the respective research stations. There is no central facility where the data is compiled and archived. Access to data is through direct contact with the scientist concerned. Data for over 30 years is available from INERA stations of Mulungu (KIVU), INERA/Yangambi and the Faculty of Agriculture, University of Kisangani, and CRSN-Lwiro (Kivu, DR Congo), University of Lubumbashi, University of Kinshasa, INERA/Kinshasa, Centre de Recherche Nucléaire de Kinshasa.

ii. Land resources. Scientists are still using the soil classification/characterization done during the colonial period and an updated database of land resources is not available. “Tervuren Museum Royale d’Afrique Centrale” and “Society Belge de géographie et de la science du sol d’outre mer” are the main institutions that have some kind of database on soil/land resources of DR Congo. Access to these data is through direct contact with these institutions in Belgium.

iii. Soil resources. The classification/characterization of Eastern DR Congo and Kivu soils has been done since a long time by soil scientists from INERA/Mulungu/INERA-Yangambi/Université de Kisangani and CRSN-Lwiro (Ex: IRSAC). However, no organized digital database of soil resources at national level is available. Access to data is through INERA/Kinshasa. To get an idea about the general characteristics of DR Congo soils, people still consult the old manual of van Wambeke: Carte de sols du Congo-Belge et du Rwanda-Urundi, Publication de l’INEAC, Brussels.

iv. Water resources. No database on national water resources is available for DR Congo. People often refer to the sectorial studies done at research stations. However, some data on water sources/ streams/river flows can be obtained from the Service National d’Hydrologie based in Kinshasa, but the quality and accuracy of the data is not very good.

v. General. There is currently no national database on agriculture in DR Congo, but information on the distribution, production and productivity of crops is available in reports and other publications. These include Vandenput (1981), annual reports and publications of the National Advisory Service (Service National de Vulgarisation et d’Animation Rurale), publications by scientists/ INERA/Annual reports, and IRAZ publications/University lecture notes.

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ERITREA

M Tesfai

1. Introduction

In Eritrea, the availability of natural resource databases is scarce and access to data and information is not yet developed due to various reasons such as lack of staff, lack of capital and equipment, poor communication and poor database management systems. Furthermore, most of the natural resources databases contain more of qualitative information and some of them contain incomplete and unreliable data. The National Agricultural Research Institution (NARI) at the Ministry of Agriculture (MoA), and training institutions like the University of Asmara and other research departments in the various Ministries, are all at a rudimentary stage of development in terms of database and modeling. Nonetheless, strengthening these institutions through capacity building, mainly through training for enhancing the skills, could lead to the improvement of databases and use of models in managing the natural resources such as climate, land, water, and soil more efficiently.

2. System modeling and decision support systems

Modeling in NRM research in general and in S&WM in particular is hardly used in Eritrea. Some PhD research projects (that were conducted in Eritrea) have attempted to use existing models and/or components of models (for e.g. water balance and nutrient balance models) in their studies but use of models beyond these studies is not reported.

3. Databases

i. Climate. Eritrea has very diverse climatic and physiographic zones ranging from arid lowlands to subhumid highland zones. Six major agroecological zones (AEZ): arid lowlands; arid highlands; moist highlands; moist lowlands; semi-desert, and subhumid zone have been identified (FAO, 1997). There is a great variability of rainfall, temperature, humidity, etc. spatially as well as with time across these diverse zones and landscapes.

There are about 110 Class 4 meteorological stations (installed by Early Warning and Food Information System of the MoA) spread over the various AEZs of Eritrea. Only rainfall is recorded at these stations and the data collected are analyzed and published quarterly in bulletin form. The Water Resource Department (WRD) in the Ministry of Land, Water and Environment (MoLWE) has installed seven 1st class meteorological stations in the typical sites of the major river basins. These stations record data on rainfall, temperature, humidity, wind and sunshine. However, these data have not been yet analyzed and made available for public use. There are other meteorological stations (established by National Meteorological Office, NMO) at nearby airports in the city of Asmara and in the port towns of Massawa and Assab. These stations have a long-term (about 100 years) climate data record (of rainfall, temperature, humidity, wind, and sunshine), but with some missing data.

ii. Water resources. Unfortunately, Eritrea is not well endowed with fresh water resources owing to the arid climate and due to shortage of rainfall. No perennial rivers (except the Tekeze-Setit River) and no surface freshwater bodies exist in the country. At present, most of the information available on surface and ground water resource potential of Eritrea is based on estimates. All the rivers and

their tributaries flow seasonally either towards the Sudanese plains or into the Red Sea. No measured data is available on the potential of tapping the rivers for irrigation and drinking water supply. The surface water quality of these rivers has also not yet been studied.

However, currently, efforts are being made by WRD to undertake an inventory of ground water wells in various parts of Eritrea – the depth of the ground water table, capacity of wells, and water quality of the wells developed. Moreover, inventory is also being done of the micro dams and water reservoirs constructed for drinking water supply and irrigation. Sedimentation loads, streams flow volume, and discharge rates for some major rivers are also being studied.

iii. Land resources. General information is available on the land resources potential of Eritrea. This refers to agricultural land use in terms of area under cropped land, irrigated land, grazing land, forested land and barren land. The Department of Land in the MoLWE has made a series of reconnaissance surveys of land use capability classification in the outskirts of Asmara and in some areas where there is high demand for land for agriculture and for construction. Land use maps have been produced for most of the villages located in the highland areas of Eritrea using GIS mapping tools. These maps are available in the archives of the MoLWE and are accessible.

iv. Soil resources. In Eritrea, no systematic survey of soil resources has been made at a national scale. FAO (1994) has produced a general soil map of Eritrea at a scale of 1:1,000,000. According to this map, 12 major soil groups have been identified using FAO/Unseco soil classification system. However, no further description about the properties and management practices of these soils has been given.

Murphy (1965) conducted a general fertility assessment of some soils of Eritrea. Soil fertility research in Eritrea has been initiated by FAO (1999) and, with the assistance of the national staff, some concept and thematic papers have been produced. Some information on soil and water conservation measures (such as terraced area, bunded fields, number of dams constructed, number of trees planted and germinated, and closure area) that have been implemented in the various AEZs of Eritrea is available in the archives of the MoA.

v. General. Most of the available information about the area harvested, yield per ha and total production for each of the major crops grown; livestock numbers; and productivity of livestock are either expert estimates or unofficial information. An irrigated agricultural production system has been practiced in Eritrea for many years. However, the history and development of irrigation and the irrigation systems practiced in different parts of the country are not well described except by Tesfai (2001), who has described extensively the Eritrean spate irrigation production system.

Most of the information on the natural vegetation resources of Eritrea is very general and lacks ground truth. Data on the forest area and grass vegetation cover are based on extrapolation and/or estimates. However, the flora of Eritrea – types and botanical description – is well described and documented. In particular, the types and distribution of the riverine forest trees in the western lowlands of Eritrea have been well documented. Deforestation in Eritrea is a serious problem but the magnitude of deforestation has been not quantified. Data on forest conservation and restoration measures (like tree planting and area closures) that are implemented in the various AEZs of Eritrea are available in the MoA archives.

Information on wildlife resources of Eritrea is also limited. Although Eritrea was once rich in wildlife, a multitude of wild animals (like elephants, zebra and ostriches) have been decimated during the war

for liberation. The types of wild animals present in Eritrea have been identified, but their numbers remain unknown.

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KENYA

Benson M Wafula and George E Okwach

1. Introduction

The traditional field experimentation approach (whether on-station or on-farm) is becoming increasingly inadequate in addressing problems related to complex agricultural systems. The conventional methods of experimentation, where multi-location trials are conducted over several years, are both time-consuming and expensive. One practical and cost-effective alternative is to use simulation models. Models enable a quick and effective investigation of a wide range of production scenarios over varying climatic and soil conditions. Over the past two decades, the crop growth simulation modeling approach using dynamic process models has been adopted in Kenya to address problems related to effective and efficient management of available natural resources (Keating et al., 1992).

2. System modeling and decision support systems

One of the most well developed and widely used models in Kenya is CERES-Maize. Its locally adapted version, CMKEN, was used to simulate maize yields comparable to those experimentally derived when tested under rainfed and irrigated conditions with varying cultivars, sowing dates, plant population and nitrogen fertiliser rates (Ritchie and Jones, 1998). Later, the DSSAT3.1 version of CERES-Maize was adjusted for waterlogging and used to assess soil fertility and climatic interactions in the maize-producing areas of Kenya. Prior to the analysis, optimum N fertiliser levels for various agroclimates were determined by taking into account anticipated maize commodity prices.

These models simulated the responses of maize crop to climate, water, nitrogen and management, but could not deal with other important features of the cropping system such as crop sequences, intercropping, runoff and soil erosion. APSIM, which is more ideally suited to examine these issues, was then adapted and applied to the semi-arid tropical Kenyan conditions with the data collected from a major collaborative project CARMASAK between APSRU, Australia and Kenya Agricultural Research Institute (KARI)-Katumani National Dryland Farming Research Centre. The Katumani research team has contributed significantly to developing the runoff and erosion modules of the APSIM model, and validation of and testing the model for a number of parameters measured for local conditions. The first formal comprehensive publication of the work with APSIM was done by Okwach (2002).

The important feature of the simulation modeling work in Kenya is the progress made in using the models for farm-level decision making. A series of sets of simulations were performed to examine the response of a given output to a range of agronomic, climatic and soil conditions. Among the earliest and most extensive uses of the simulation approach in Kenya was its adoption by Wafula (1993) to evaluate response farming, a tactical scheme proposed by Stewart and Faught (1983), to minimise climatic risk associated with maize farming in eastern Kenya. Models were also used to identify optimum N fertiliser levels for various agroclimates and long-term yield distribution and management options.

3. Databases

i. Climate. The main source of information about climate is the Kenya Meteorological Department (KMD). The KMD holds data records from as far back as 1926, that comprise information on

precipitation, temperature, solar radiation, sunshine hours, relative humidity and wind speed. Of 1200 weather stations, only about 40 collect all the information indicated above. So far, only the precipitation data is in digital format. This information is available to researchers and other users on request.

The Kenya Agricultural Research Institute also runs the Agrometeorological weather stations located within its research centres countrywide. Information gathered at these centres is readily available to local scientists. All the weather data collected at KARI centres for the past two years is in digital format.

ii. Soils. The major database on soils in Kenya is the Exploratory Soil Map of Kenya at a scale of 1:1000000, which is not precise enough for most research applications. Although it provides a characterization of soils in major agricultural districts, it does not indicate area covered by different soil types. The only other significant soil-related database is the information that was gathered under the Fertilizer Use and Recommendation Project conducted in throughout the country between 1985 and 1988. The project provided an agroecological zonation and description of the high and medium potential areas of Kenya based on existing information on water availability, temperature and soils. The information is gathered from 60 sites, which are highly or moderately representative of approximately 70% of the high and medium potential areas of Kenya.

iii. Agriculture. The Maize Database is a set of information that characterizes maize cropping systems in Kenya. Because the database was intended to characterize the spatial diversity in maize systems as well as to reflect the underlying determinants of national maize production, the maize sampling frame combined elements of both spatial-and population-based sampling frames. Spatial stratification of maize production areas by agroclimatic attributes produced a zonation scheme for maize adaptation.

Another database, the *Agroecological Land Resources Assessment for Agricultural Development Planning – a Case Study of Kenya*, is concerned with the development and implementation of a national level methodology for the determination of land use potentials of land resources in each of the 41 districts in Kenya, as a tool in policy formulation and development planning. The Food and Agriculture Organization (FAO) and the International Institute of Applied Systems Analysis (IIASA) conducted this case study in collaboration with the Government of Kenya. The database holds information on land resources, soil erosion and productivity, agroclimatic and agro-edaphic suitability for barley, oats, cowpea, green gram and pigeonpea; crop, fuelwood and livestock productivity; and district level assessment of crop productivity.

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MADAGASCAR

Ndrianja Jemisa Rarojoson

1. Introduction

Nearly 70% of Madagascar's population depends on low-productivity but extensive agriculture on marginal lands for its livelihood, leading to degradation of resources. The National Centre of Farming Development (FOFIFA), through six research departments, Departement de Recherches Agronomiques (DRA), Departement de Recherches Zootechniques et Veterinaires (DRZV), Departement de Recherches Forestieres et Piscicoles (DRFP), Departement de Recherches Technologiques (DRT), Departement de Recherche-Developpement (DRD), and Departement de Recherches Rizicoles (DRR), is responsible for conducting research at its headquarters in Antananarivo and at eight other regional research centers. The main focus of the research is on crop production and rice is the most researched crop, being studied by about half of the country's crop researchers. Deforestation and soil erosion are amongst the most serious of Madagascar's natural resource problems.

2. System modeling and decision support systems

In Madagascar the use of models in S&WM research is very limited or nonexistent. Any use of models in research is confined to the work conducted by specialist institutions like the International Rice Research Institute and the national system does not have the capacity to adapt/calibrate/ validate and apply simulation models and DSS to conduct scenario analysis to assess soil water technologies.

3. Databases

i. Climate. The Meteorological Service is responsible for collecting, processing and disseminating information on climate and weather. Rainfall in Madagascar varies from levels like that of tropical rain forests to near desert conditions. The country is divided into three major ecoregions, the Highlands, the West Coast and the narrow East Coast. Because of the high altitude, in the Highlands the dry season (June-October) is cool, which limits crop production. The West Coast is hot and the dry season is very long, up to nine months in the far southwest. Rainfall can be less than 400 mm yr^{1}. The East Coast is warm and humid, with rainfall that sometimes exceeds 3000 mm yr^{1}, and with almost no dry season. The country has 24 synoptic stations that collect data on temperature, precipitation, humidity, pressure, sunshine and evaporation. The meteorological service conducts various studies in collaboration with the World Meteorological Organization (WMO) and other international organizations. Data is accessible through the service.

ii. Soil resources. The National Centre of Farming Development (FOFIFA) collects and manages information on soil. The soil profile database includes information on location, soil depth, soil chemical and physical characteristics, and soil characterization. Because of limitations of budget and nonavailability of trained staff, only a part of the country is covered.

iii. Water resources. The National Centre of Research on Environment (CNRE) manages data on water resources. Madagascar has good water resources. The two major basin groups have been identified; one draining to the west into the Madagascar Channel and the other to the east into the Indian Ocean. The renewable water resources are estimated at 337 km^{3} yr^{1}, which is almost 15 times

the total water required for the development of the irrigation potential. Nearly 70% of the 1.5 million ha area identified as having irrigation potential has already been brought under irrigation.

iv. Agriculture. Most global datasets like those from FAO, the World Resources Institute (WRI) and other institutions include data on the area, production and productivity of the crops in the country. The national government also collects and publishes census on agricultural sector.

RWANDA

Kagabo Désiré Mbarushimana

1. Introduction

A large number of public institutions, including three ministries and funding organizations, are involved in soil and water resources management in Rwanda. However, poor coordination between these organizations has resulted in improper planning and inadequate use of available resources. To achieve much needed poverty alleviation through sustainable development and use of available resources, the issues of land and environmental degradation must receive high priority. The Government of Rwanda is currently developing a National Master Plan for marshland development, watershed protection and soil conservation, the main objective of which is to compile the natural resources and land use data and build a national database for use with appropriate modeling or DSS tools.

2. System modeling and decision support systems

There are very few initiatives related to the development and use of system simulation tools in Rwanda. As Rwandan agriculture suffers from erratic distribution of rainfall across the seasons, some attempts were made by the National Meteorological Service to predict rainfall using early warning models under the Rwanda FEWSNET Project and also using the ETA model. The new master plan of the Government of Rwanda, with an overall objective of planning for conservation of natural resources, is using GIS tools. Another related project is a study for Nyabarongo and Akanyaru valleys wherein a mathematical (hydraulic) model has been developed. The DSS component of the Nile Basin Initiative Project also involves the development of models for natural resources management.

The ISAR agro-meteorology service, which was in charge of studies on crop growth simulation, is no longer in operation. Prior to 1994, it was involved in assessment of crop water needs for the eastern region (mainly semi-arid), using FAO water balance method. No other study has dealt with crop growth simulation or developed a model for this purpose.

The GIS and Remote Sensing Centre of the National University of Rwanda (NUR) is involved in developing DSS by integrating simulation models with GIS under projects such as Gishwati deforestation impact assessment and eco-tourism potential of Nyugwe forest.

3. Databases

i. Climate. From 1907 to date, meteorological data are available for more than 100 stations distributed throughout the country. The data processing centre at the headquarters of the National Meteorological Service compiles all the data in a database and processes these using appropriate software tools. The database includes data on rainfall, relative humidity, temperature, wind speed, sunshine and evaporation.

ii. Land resources. The last assessment of land cover in Rwanda was made in 1987 when TECHNOSYNESIS took aerial photographs for mapping purposes. However, recent estimates on land cover showed that important changes have taken place over the last thirteen years. These estimates are presented in the document entitled *Cadre de la formulation de la stratégie de developpement agricole*. This data is available in the database of Division des Statistiques Agricoles (DSA)/Food Security Research Project (FSRP) – MINAGRI. Regional level studies by

AFRICOVER/FAO project also developed a database, which is available on CD and includes data on land cover, land form, roads, rivers, maps and reports and other tools.

iii. Soil resources. The soils of Rwanda have been studied by the project Carte Pédologique du Rwanda (CPR) (1980-1990). All data related to soils are available in this project database and maps of soil (1:250,000), pedology (1:50,000) and geology (1:250,000) were produced.

iv. Water resources. The hydrology department of the Ministry of Mines and Natural Resources is currently developing a database using data that has been collected from the 1950s. This includes meteorological, hydrological and water use information. The project on characterization of the Rwandan Watershed was conducted in 1998. The results obtained are available in a database named Bassin Versant that presents a series of parameters for the 352 watersheds that form the hydrologic network of the country.

v. Agriculture. Prior to the 1994 war, Rwanda's agricultural database was one of the best in the African continent, with a consistent time series data on production, area, and yield spanning the period from 1984 through 1992 (Kelly et al. 2001). This database, drawn from annual surveys of a nationally representative random sample of approximately 1,240 farm households, was supplemented with a variety of specialised surveys conducted intermittently on topics such as input use, livestock production, natural resource management practices, and non-farm income. These surveys were disrupted in 1994 and resumed in 1999 by FSRP and the DSA of MINAGRI. These surveys aim at updating the database on agricultural statistics and improvement of MINAGRI's capacity to collect, process and analyse the data to help in the planning and management of resources in a way that contributes to the promotion of food security in Rwanda.

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SUDAN

Abdel Magid Ali El Mobarak

1. Introduction

The use of system models and DSS in Sudan is limited and the potential of these new information tools in research, education and development activities remain unexploited. However, there is a great interest in this work. This paper presents an overview of the existing situation with respect to model development, adaptation and validation work in the country.

2. System modeling and decision support systems

The CROPWAT program developed by FAO is used in agroclimatic studies in Sudan. Other programs used are mainly to calculate the length of growing period and the probabilities for the time of onset of the rainy season at different locations. Some work with linear and nonlinear simulation models to simulate the flow and storage relationships of the Blue Nile has also been initiated.

The Land and Water Research Centre (LWRC) of the Agricultural Research Corporation (ARC) of Sudan assessed the suitability of the land for various uses using the Manual for Land Suitability for Irrigated Agriculture in Sudan. Another attempt was using software called Winsurf with maps on elevation and the chemical properties of the soils in Kenaf scheme. Land suitability classification studies were conducted for surveyed areas to assess the agricultural potential of different soil types for crop production.

Agricultural Research Corporation scientists conducted many research studies on the current use of the available water resources and opportunities for improved utilization of the same. The ARC library contains many reports and papers on crop water requirements, water use efficiency, irrigation intervals, and quantity of water per irrigation. However, use of this information in developing/ adapting crop growth models has not been reported.

3. Databases

i. Climate. A big dataset of climate data covering more than 100 stations all over the country is available with the Sudan Meteorological Department based in Khartoum. The department produces and publishes annually 10-year and sometimes 30-year averages for different stations. The data is very expensive to obtain on a daily basis. The dataset includes information on maximum and minimum temperature, relative humidity, sunshine duration, wind speed and direction, rainfall and evaporation.

ii. Land resources. The dataset on land resources is a combination of soil and climate data and is available in the form of tables, reports and maps. Using this data, the LWRC of the ARC has prepared several reports covering many parts of Sudan and the same are available on request (Adam 2000).

iii. Soil resources. The soil database which contains information on profile data, site description, and physical and chemical properties for most soils of Sudan is available with the LWRC in the form of reports and maps (Karim 1998). Data from the Gezira scheme is available in digital form.

iv. Water resources. Sudan is rich in water resources (Adam, 1996) and the Ministry of Irrigation and Water Resources maintains good records on the water resources of Sudan. The rainfall in the

country varies from near zero to 1800 mm. The major surface water available to the country is from the River Nile and its tributaries with an annual discharge of 84×106 m^3 of which the Sudan have 18.5×106 m^3 as per the Nile Water Agreement calculated at Aswan and 20×106 m^3 calculated at Sennar. Preliminary studies indicated that Sudan is also rich in ground water resources, with an aquifer covering about 50% of the total area of the country.

v. Agriculture. The Agricultural Statistics Administration of the Ministry of Agriculture and Forestry of Sudan annually reproduces reports on the production situation of the country in tabulated and report form covering all production sectors (irrigated and rainfed).

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TANZANIA

SD Tumbo, S Mwakalila, OB Mzirai, FB Rwehumbiza, and N Hatibu

1. Introduction

There is a long history of S&WM development programs in Tanzania. Examples of soil water management development programs as described in Kisanga (2002) include the East Usambara Conservation and Agricultural Development Project which started in 1987; Environmental Conservation in Iringa (Hifadhi Mazingira Iringa – HIMA) started in 1990; Dodoma Land Use Management Project started in 1991; Shinyanga Soil Conservation and Afforestation Project (Hifadhi Ardhi Shinyanga – HASHI) started 1986; Land Management Programme for Environmental Conservation (LAMP) started in 1991; and Soil Conservation and Agroforestry Project in Arusha (SCAPA). Other projects are: Dodoma Region Soil Conservation Project, Smallholder Development Project for Marginal Areas and Sustainable Management of the Usangu Wetlands and its Catchment (SMUWC) project. Unfortunately, there has been very limited use of models and databases in most of the programs described above.

2. System modeling and decision support systems

There are several models that are currently being used to a limited extent, mainly in universities and research institutions. Some of the models/DSS are Transfer Function Model (TFM), Xinanjiang, HBV, and the Pitman Model used at the University of Dar-es-Salaam. The TFM is a program for analysis of rainfall-discharge from catchments and is based on mechanistic modeling concepts suggested in the work of Stigter and Beck (1994) and Young and Beven (1994) in humid regions. The model accounts for the key hydrological responses, but avoids the problem of over-parameterization. The Xinanjiang model was developed in 1973 and published in 1980 (Zhao et al. 1980). Its main feature is the concept of runoff formation on repletion of storage, which means that runoff is not produced until the soil moisture content of the aeration zone reaches field capacity, and thereafter runoff equals the rainfall excess without further loss. The Pitman rainfall-runoff model was developed in South Africa, and it is currently used mostly in SADC regions. The model is based on monthly flows.

The SWMRG of the Sokoine University of Agriculture in collaboration with University of New Castle Upon-Tyne have developed a rainwater-harvesting model called PARCHED-THIRST (Predicting Arable Resource Capture in Hostile Environments during the Harvesting of Incident Rainfall in Semi-Arid Tropics). The model is user-friendly and process-based, and combines the simulation of hydrology with growth and yield of a crop on any number of distinct or indistinct runoff producing areas (RPAs) and runoff receiving areas (RRAs). The landscape is divided into units (or profiles), which are assumed to represent homogenous portions of the landscape (or system). The only transfer of mass between profiles is runoff (Young et al. 2001).

The SMUWC project, which ended in 2001, was developing the Usangu basin model (SMUWC 2002). The model is composed of four sub-models: hydrological routing model (HRM), swamp hydrological model (SHM), high catchment rainfall-runoff model (HCRRM) and irrigation impact model (IIM). In addition, the RIPARWIN (Raising Irrigation Productivity and Releasing Water for

Intersectoral Needs) project is developing a decision support system that will allow the river basin water office, zonal irrigation office and Mbarali District irrigation office to make the right decisions in managing water resources in the Usangu river basin.

The Lake Victoria Decision Support System (LVDSS) is a comprehensive decision support software for the visualization of spatial and temporal data, planning of agricultural production, simulation of watershed hydrology, regulation of lake level, and operation of the Owen Falls hydroelectric power in the Lake Victoria Basin in eastern Africa (GTRC 1999).

3. Databases

i. Climate. A central database on climatic data is available at the Tanzania Meteorological Agency (TMA). The data is collected through a network of:

- Synoptic stations, which deal with surface and upper air observations. Data on rainfall and temperature are recorded in digital format; other data are in analog format.
- Agro-meteorological stations owned jointly with the Ministry of Agriculture, and used to monitor all meteorological parameters.
- Climatological stations that monitor daily rainfall and temperature.

ii. Land resources. There are four main types of land resources databases in Tanzania. These are:

- *Land mapping and surveys:* The basic available database is topographical maps of scale 1:50,000. Most of this data is in analog format and available from the Ministry of Lands.
- *Land cover classification:* This database is currently under development by the Institute of Resource Assessment (IRA). It is based on Landsat Thematic Mapper data corrected to fit topographical maps at 1:250,000 scale. Image interpretation is being supported by ground truthing that was conducted in 1994.
- *Geology:* In Tanzania geological data is mostly available in *quarter degree* sheets at a scale of 1:125,000 from the Ministry of Energy and Minerals. Most of the data has been obtained from field surveys and is in analog form.
- *Soils:* A general-purpose soils map has been developed through interpretation of satellite imagery coupled with ground truthing for the whole country at scale of 1:2,000,000 and is available at National Soil Service at Mlingano, Tanga.

iii. Water resources. The Ministry of Water maintains two types of digital databases consisting of hydrometric and hydrogeology data. The hydrometric data is collected from hydrometric stations in major rivers in Tanzania. Parameters that are recorded are limited to water levels and flow rates. The hydrogeological data monitored/collected include aquifer type, water levels, drawdowns, yield, and location and size of boreholes.

iv. River basin database. In Tanzania, databases have also been developed for river sub-basins, such as the database established by the SMUWC project. The database is comprised mainly of data on Mbarali District and includes general information, reports and research data organized under five different sections. Another database available in the country is the one being developed by RIPARWIN project (Raising Irrigation Productivity and Releasing Water for Intersectoral Needs).

The database, organized into six sections, will include data on water, irrigation, climate, hydrology and institutions, and economic data, along with general information about the area.

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UGANDA

Drake N Mubiru

1. Introduction

In Uganda, modeling work goes as far back as the 1940s. Several crop growth simulation models have been used over the years for academic purposes, but few for agriculture development. This is attributable to the fact that attempts at model development, calibration and evaluation have been, in most cases, undertaken by students in postgraduate training. Thus after their training there is no follow-up to their developments and their findings usually remain on shelves as theses. This state of affairs is due to the fact that Uganda as a country does not have a program focused on model development and utilization. Furthermore, the two decades of civil unrest adversely affected the infrastructure for data collection and its management. The new Plan for Modernisation of Agriculture (PMA) envisages that agricultural transformation in Uganda will lead to poverty eradication through a profitable, competitive, sustainable, and dynamic agricultural and agro-industrial sector. This endeavour would immensely benefit from systems simulation modeling, which allows delivery of information to decision-makers in a format for direct use in problem solving.

2. System modeling and decision support systems

The following are some of the models that have been developed/adapted and used in Uganda over the past two decades.

Rainbow: Designed to test the homogeneity of hydrologic records and to execute a frequency analysis of rainfall and evaporation data. The program is especially suitable for predicting the probability of occurrence of either low or high rainfall amounts, both of which are important variables in the design and management of irrigation systems, drainage network and reservoirs (Raes et al. 1996).

Nutmon Toolbox (Monitoring nutrient flows and economic performance in tropical farming systems): Toolbox allows comparison of development options by bringing in 'better' farming systems based on integrated nutrient management (INM) technologies (De Jager et al. 2002).

PLAR (Participatory Learning and Action Research) Resource Kit: This model is being used in Ikulwe, Mayuge District by CIAT to monitor resource flows based on extensive work done in several African countries.

Soil Productivity Model: This model is one of the very few that has been developed at Makerere University. The basic model components include soil productivity as a crucial indicator of soil resilience. Crop yield over time is used as a measure of productivity. Long-term crop performance under specific environmental and management conditions is mainly dependent on Relevant Soil Depth (RSD) characteristics.

Upflow: Simulates water movement in a soil profile from a shallow water table to the topsoil (capillary rise).

IRSIS (Irrigation Scheduling Information System): Plans irrigation schedules for different operational conditions and calculates the yield response under rainfed agriculture using historical data.

DSSAT (Decision Support System for Agrotechnology Transfer): Comprises of several crop performance models, which can be used to simulate crop growth and development, soil water

dynamics and soil nitrogen dynamics in response to weather, soil characteristics, cultivar characteristics and crop management with a daily time step from sowing to maturity.

Stics: This generic model for simulating crops and their water and nitrogen balances is being used to evaluate banana management.

Agricultural Non-point Source (AGNPS) Pollution Model: This is an event-based model that simulates surface runoff, sediment, and nutrient transport primarily from agricultural watersheds. The nutrients considered include nitrogen and phosphorus, both essential plant nutrients and major contributors to surface water pollution. Basic model components include hydrology, erosion, and sediments and chemical transport.

Quefts (QUantitative Evaluation of the Fertility of Tropical Soils): Coupled with soil analysis results it provides quick estimates of nutrient requirements (Janssen et al., 1990).

3. Databases

i. Climate. The National Meteorological Department of Uganda maintains at least one meteorological center in each of the agroecological zones for the purpose of data inventory of environmental resources with regard to climates. According to Komutunga and Musiitwa (2001), there used to be approximately 20 well-equipped weather stations distributed over the country and they provided the basic data to calculate Penman's estimate of evaporation. Currently, most of them need rehabilitation; that notwithstanding, observations are recorded on a daily basis and checked and standardized by the national meteorological department in Kampala. This data is automated into a machine-readable database at Namulonge Research Institute and is analyzed statistically for daily, ten day, monthly and annual means. The results are mapped out for land use planning, defining strategic planting dates, frequency of dry spells, calibration, and validation of crop weather models (Komuntunga and Musiitwa, 2001).

ii. Soil resources. Most of the information about soil in Uganda is based on the Reconnaissance Soil Survey of Uganda of the early 1960s (Cheney 1960) in which each soil unit is given an approximate potential productivity rating. The analytical data of the different soil profiles from this first survey is now available in both soft and hard copy. There is also an old non-digitized soils map, which is currently being updated and digitized. In its old form, this information has been very difficult to access and had no provision for updating. The Soils Program at Kawanda Agricultural Research Institute is building a National Soils Reference Database. The process involves updating the old information by correlating the local soil classification system with FAO/ UNESCO nomenclature. So far several maps have been digitized and for each sheet other components (e.g. meteorological, soil survey, land use/socioeconomic and biodiversity data) are being incorporated.

The Soils Program is also building capacity in database management and model development. As of now, one research officer has attended a modeling course organized by the International Fertilizer Development Center (IFDC). Other officers and technicians have been introduced to crop-soil simulation models like DSSAT, STIC and NUTMON TOOLBOX.

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C. Identified constraints to model development and use in the country

The presentations by the country representatives summarized well the status of development and use of simulation models and DSS in various countries in the region. The presentations have highlighted the significant differences existing among the member countries in their exposure to these new research tools and in making use of the opportunities provided them. While some countries like Kenya and Tanzania are more advanced, some others are completely ignorant or have had very minimal exposure. Several of the constraints identified by the individual countries are similar and they include:

i) Lack of skills and availability of trained staff
ii) Lack of availability of resources, both financial and institutional
iii) Ignorance and lack of awareness/knowledge
iv) Lack of availability of and access to good quality datasets
v) Lack of availability of models appropriate to the local conditions
vi) Complicated models are not user friendly
vii) Poor communication systems
viii) Lack of coordination among the institutions within the country and in the region
ix) Civil unrest, wars etc.

D. Suggestions for future opportunities, needs and the way forward

Although there are significant differences in the level and extent to which simulation models/DSS are used in various countries in the region, the region as a whole has considerable expertise in this area of research. However, lack of coordination among the researchers is leading to improper utilization of these experiences and in some cases leading to duplication of efforts. The first task, therefore, is to encourage collaboration between the institutions in various countries engaged in the development and use of models so that available resources are better utilized by taking advantage of the complementarities. A joint effort to address the major problems like erosion, land degradation, rainwater management, and soil fertility management is likely to yield better results than the individual efforts.

A large number of models capable of simulating the effects of various processes and their interactions on the productivity and long-term sustainability of diverse agricultural systems practiced in the region are readily available. It may be more cost effective to use the existing models through collaborative research with international institutions than to develop new ones. These models however differ in their complexity, input data requirement, scale of application, and adoption in the region, and in support from the model developers for their adaptation to local conditions. Hence selection of appropriate model(s) based on the identified needs, and building national capacities to apply and use the selected models is another important task.

The quality of the model outputs, to a large extent, depend on the quality of the input data. Efforts are therefore required to develop good quality databases with information on all the parameters that are essential for validation and application of the models selected as appropriate to the region. This requires a sincere and well-coordinated effort between the nations in the regionand between institutions within the nation. Mobilizing necessary financial and institutional support to such an activity is another challenge.

Annex 3: Summaries of Issues Papers

Research and development in the management of soil and water: the role for models

FBR Rwehumbiza, OB Mzirai and SD Tumbo

Introduction

The objective of improving the livelihoods of the rural population of SAT depends upon the adoption of new ideas, new technologies and better management practices by millions of resource-poor, small-scale farmers. Agricultural support services, therefore, are required not only to identify useful innovations but also to make them available to farmers at all locations where they are likely to succeed (Gowing et al. 2000). In the conventionaltop-down approach to technology transfer, public sector researchers develop new technologies on research stations, which are then promoted by the extension services. Many seemingly perfect soil conservation initiatives have been rejected and a noteworthy study by Hudson (1991) for FAO attempted to explain the frequent failures.

Sustainable development depends upon willing adoption rather than coercion, but it is equally undesirable to adopt a 'supermarket strategy' of placing new technology packages on the shelf for the 'buyer' to collect (Gowing et al. 2000). Rather there is a need for professionals involved in development to reconsider the process. A new 'farmer-first' paradigm is becoming widely accepted (Chambers et al. 1989, Scoones and Thompson 1994). This approach emphasizes the participation of farmers at all stages in the process of innovation and is located in the farmers' fields. Both the traditional and the participatory approaches demand time-consuming and costly experimental work in order to arrive at the technology options, which seem most likely to work. These experiments are, of necessity, restricted to certain locations over limited time intervals and extrapolation (spatial and temporal) is always a problem.

If we exhaustively study all possible factors affecting crop growth on one location and come up with a suitable combination of factors which optimizes yield, can we expect to replicate success in another location? There are a number of issues one may wish to consider before responding to this question: Are soils similar? Is the climate the same? Is the topography of the new site similar? Are management practices the same?

Variability in environmental conditions makes it difficult to use experimental results from one place in time to another place at another time (Van Keulen 1995).To confidently solve the above problem, one would have to conduct similar studies on the new location as those carried out on location "1". Unfortunately, there are very limited resources in terms of funds, human capital, and time to physically investigate all conceivable factor combinations at all locations. Furthermore, the urgent need of the day is answers to farmers' problems.The only feasible solution is to use models that can test "what if'' scenarios. Models offer cheaper and quicker computational results, thus allowing the evaluation and testing of various technologies.

Uses of models in research

Apart from using models to solve the problem of transferability of research findings, Seligman (1990) identified three key areas where research uses models:

- The identification of gaps in knowledge
- The generation and testing of hypotheses – to aid experimental design
- The determination of the most influential parameters of a system, on which research should concentrate its efforts (sensitivity analysis)

Models are thus a way of setting our knowledge in an organized, logical dynamic framework, allowing identification of faulty assumptions and providing new insights. Matthews (2002) has written comprehensive reviews on the use of models. In summary, he regards models as tools in research, in crop management, and in cropping and farming systems.

Challenges in the use of models

The usefulness of models has been articulated above; however, their use in ECA is still very limited for a number of reasons:

- Basic site-specific data required to run S&WM models is limited, especially in the areas of soil and crop coefficients. Where available, the data is not in readily retrievable forms.
- Most models have been developed outside Africa; thus there is limited knowledge of modeling and use of models. Research and academic institutions are the main users of models.
- The extension staff, policy makers and farmers, who are the active implementers of S&WM technologies, continue to be sidelined with regard to use of models, leading to low impact.

Conclusions

Experimental research into S&WM, whether on a research station or on farmers' fields, is necessarily restricted to specific sites over limited time intervals and meaningful extrapolation is a problem. Given the inherent limitations of the experimental approach, simulation models should be used to permit easy spatial and temporal extrapolation as well as in testing sustainability of S&WM technologies. Models are useful tools, and their increased use in research and strategic planning should be promoted.

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Application of simulation modeling in smallholder farming systems: A case study to evaluate crop improvement technologies in Zimbabwe's Semi-Arid Tropics

John Dimes

Introduction

A major theme for the proposed SWMNet is increased water use efficiency (WUE) for smallholder farming systems in Eastern and Central Africa. While improved management of excess water is a research priority in humid regions, improved management of water deficits is the priority for cropping systems in SAT regions. Over the last 20 years, there has been considerable research investment in pursuing the latter through improved germplasm (short-season cultivars) and improved soil conservation technologies that incorporate water harvesting and/or water retention. However, the impact of these technologies on improved WUE is strongly dependent on fertility management, and seldom are the associated interactions adequately understood or easily quantified.

This paper reports the use of a cropping systems model to compare and contrast the productivity gains from investment in improved germplasm and small inputs of N fertilizer in dry regions and how the technology responses translate into improved WUE. The analysis presented focuses on maize in Zimbabwe, where 85-90% of farmers use hybrid maize seed, maize being the favored crop for investment by smallholder farmers, even in drier regions.

Material and Methods

The cropping systems model used in this study is APSIM, the Agricultural Production Systems SIMulator (McCown et al. 1996, Keating et al. 2002). Using APSIM v1.61, the analysis explores the response of short-season maize to fertilizer on a shallow sand (PAWC = 60mm) of medium fertility (OC% = 0.8) in Zimbabwe. The weather record used was for Bulawayo (latitude 20.2°S) extending from 1951 to 1999 (48 crop seasons, Nov-Apr, annual rainfall = 590mm). Seasons were simulated independently by re-initialization of water and N (PAW = 0, mineral N = 9 kg N ha^{-1}, OC% = 0.8) at sowing on 1 December each year. Plant population was 2 plants m^{-2}. All crop residues were removed at harvest.

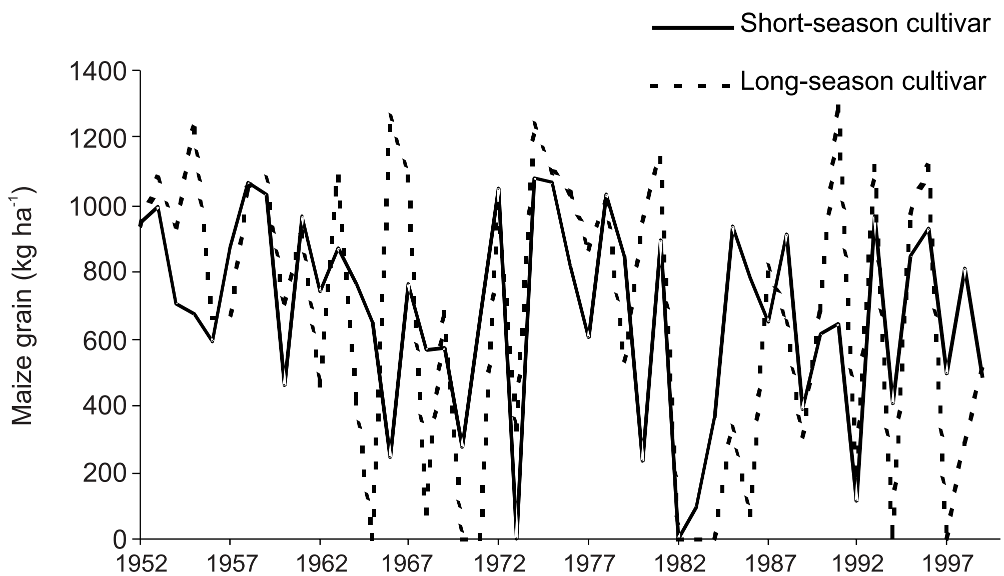
The baseline for comparison is a long-season maize cultivar with no N inputs (all other nutrients are assumed nonlimiting and there are no pest and disease constraints). The short-season maize cultivar is SC401 and the fertility input is 1 bag of Ammonium Nitrate fertilizer (17.5 kg N ha^{-1}) at 35 days after sowing (das).

Water use efficiencies (kg grain mm^{-1} in-crop rain) are calculated using simulated grain yield and the amount of rainfall between sowing and harvest. It should be noted that since phenology varies between cultivars, and is sensitive to N stress, varying amounts of rainfall are sampled for the various N and germplasm combinations simulated in this study. Hence, the average in-crop rainfall for the short-season cultivar is 385mm and for the long-season cultivar, 440mm.

Results

Germplasm comparisons

Simulated maize yield for long- and short-season cultivars with no N inputs is shown in Figure 1. The simulated long-term average grain yield for both cultivars is low (long = 664 kg ha^{-1}, short = 680 kg ha^{-1}) and the year-to-year variability high, although substantially less for the short-season cultivar (stdev = 298 kg ha^{-1})) compared to the long (stdev = 436 kg ha^{-1}) .



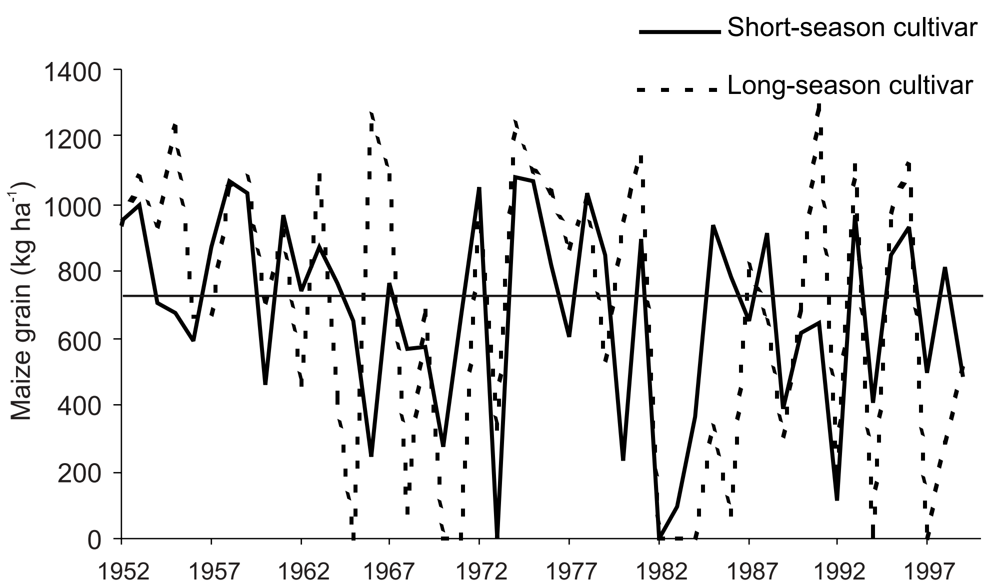


Figure 1. Simulated maize grain yield for long and short-season cultivars with no N inputs at Bulawayo for cropping seasons 1951 to 1998.

Due to the effect of variable rainfall distribution, no technology performs best in every season. In Figure 2, results in Figure 1 are converted into an annualized difference for the cultivar responses. The effect of applying N fertilizer is also included in Figure 2. A positive value in any year represents the yield advantage in that season for the technology indicated above the x-axis, and a negative value, the yield advantage of the alternative technology indicated below the x-axis.

With no N applied (Fig 2a), the yield advantage of the short-season cultivar averages 300 kg ha^{-1} and is achieved in 48% of years. In comparison, the long-season type has an average yield advantage of 250 kg ha^{-1} and is achieved in 52% of years. If a small amount of N is applied (Fig 2b), then there is a

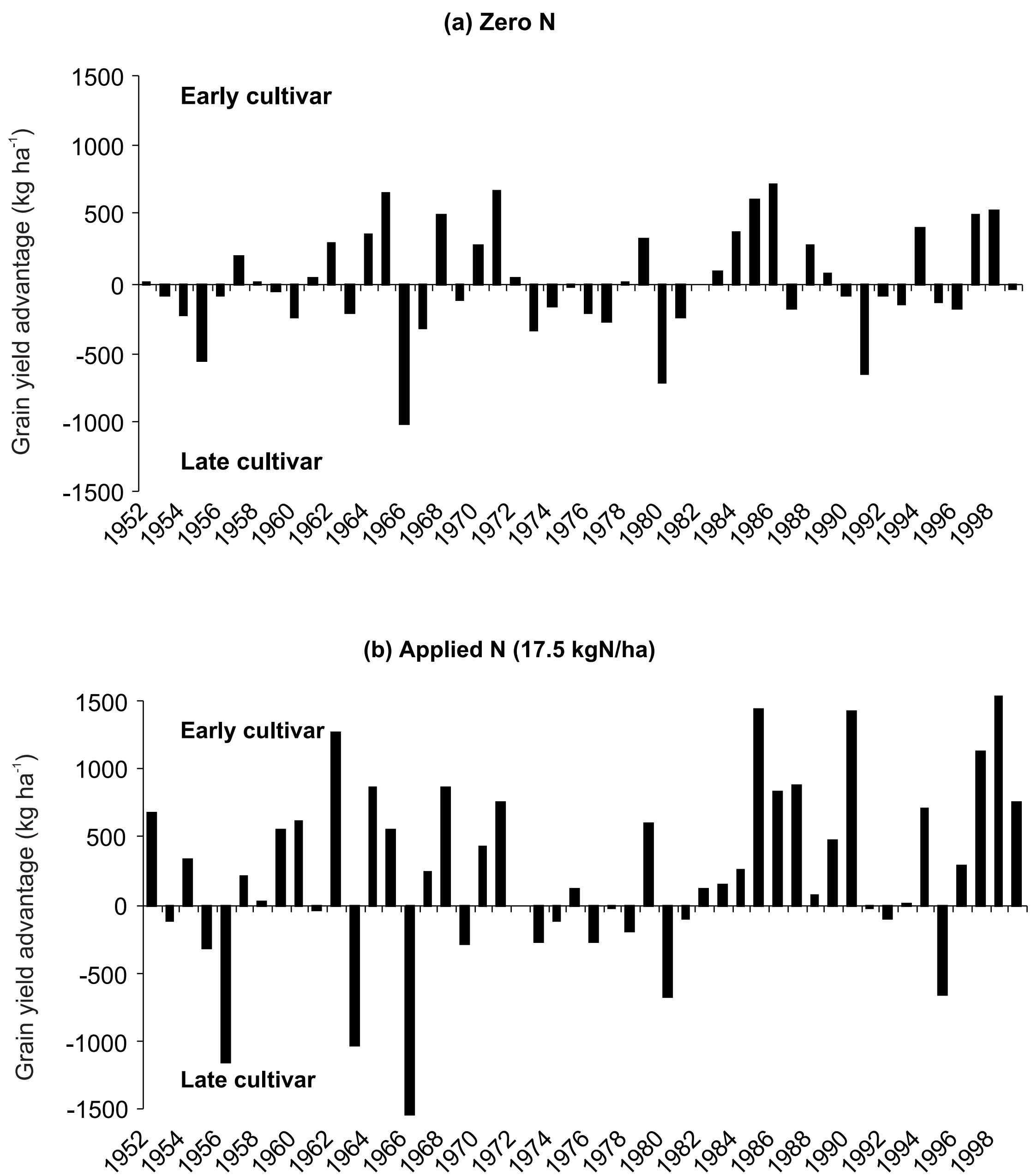


Figure 2. Annual grain yield difference between short and long duration maize cultivars simulated for Bulawayo, (a) without and (b) with N fertilizer applied.

considerable shift in favor of the short-season cultivar – average yield advantage is 600 kg ha^{-1}, and an advantage is seen in 60% of years. But in 40% of years, the long-season cultivar still outperforms the short-season cultivar by an average of 390 kg ha^{-1}.

N fertilizer comparisons

The benefit of a small amount of N fertilizer on crop yield in rainfed systems is shown in Figure 3. With N applied, the average grain yield increase compared to zero N is 600 kg ha^{-1}, and an increase is achieved in 92% of years. The negative effect of N inputs on crop yield, a common concern of farmers in drier regions, is estimated to occur in 8% of years. In these seasons, crop yield without N fertilizer outperforms crops with N by an average of 120 kg ha^{-1}.

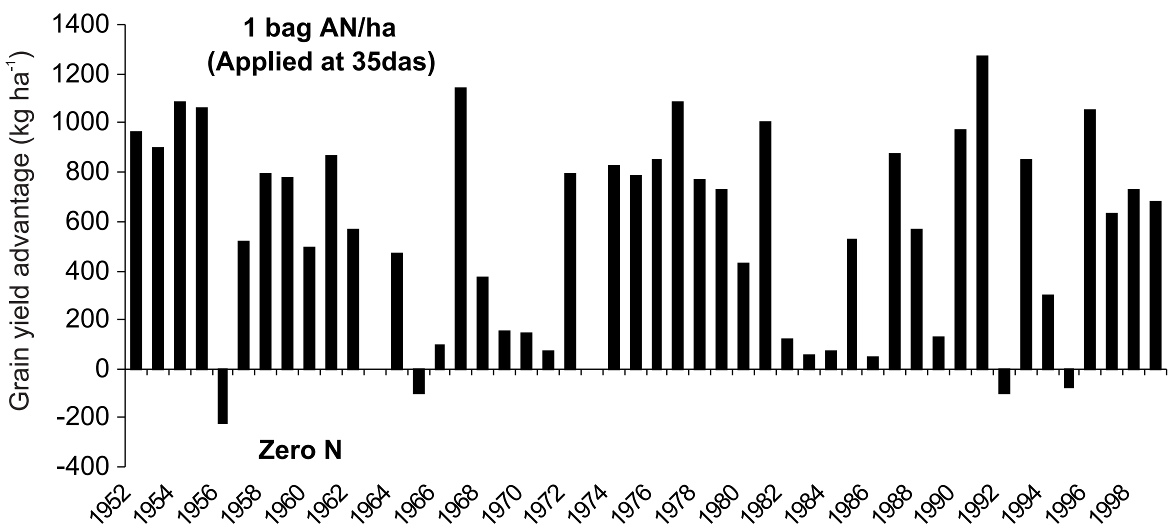


Figure 3. Annual grain yield difference between 1 bag ammonium nitrate (17.5kg N ha^{-1}) applied and zero N applied to short-season maize simulated at Bulawayo.

Impact of technologies on WUE

The average WUE calculated from 48 simulated maize crops for a range of combinations of technology options are shown in Table 1. It shows very low average WUE (1.5) for a traditional

Table 1. The average WUE calculated from 48 simulated maize crops for a range of combinations of technology options.

Technology option	WUE (kg grain/mm rainfall)
Long-season cultivar, zero N	1.5
Short-season cultivar, zero N	1.8
Long-season, N applied (17kg ha^{-1})	2.1
Short-season, N applied (17 kg ha^{-1})	3.2
Long-season, water conservation, N applied	3.7
Short-season, water conservation, N applied	4.5

farming system utilizing long-season cultivars with no N inputs. The results also show that there is only a marginal increase (20%) in WUE with a short-season cultivar if no N is applied.

If a small amount of N is applied, there is a 40% increase in WUE for the long-season cultivar, and almost 80% increase for the short-season, when compared to the WUEs at zero N for the respective cultivars. These results suggest that a traditional long-season cultivar has lower N responsiveness than a short-season cultivar. As expected, there is enhanced WUE if N application is combined with moisture conservation, and again the short-season cultivar is most favored (4.5 kg grain/mm rainfall). However, it is worth noting that this maximum WUE is still considerably below the typical WUE for the environment (10-12 kg grain mm^{-1}) achieved with high input systems.

Conclusions

Despite decades of investment in breeding short-season crop cultivars, and current trends to substantially increase research investments to improve seed delivery systems for smallholder farmers, returns on these investments, even for dry regions, will continue to be severely restricted unless farmers can be encouraged to invest in soil fertility. This outcome is already in evidence with the situation in Zimbabwe, where despite widespread uptake of hybrid maize, smallholder yield levels in the SAT remain in the range of 500–1000 kg ha^{-1}. In other words, farmers are making very poor use of the rainfall that they do receive each season because of their low levels of investment in soil fertility management.

The WUE analysis provides supporting evidence that crop productivity in smallholder farming systems can be substantially increased by an integrated genetic, nutrient and water management approach. However, it also separates and quantifies the payoffs to incremental uptake of the technology options and this information may be more practical to smallholder farmers facing severe resource constraints by helping to better prioritize their investment choices.

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Better management of climate variability using simulation models and seasonal climate forecasts

KPC Rao

Managing risks associated with variable seasonal rainfall is essential for intensification of agriculture in the ECA region, where farming is predominantly rainfed. Throughout the region rainfall is subject to pronounced variability from year to year, and rainfall during the crop season varies from about $^{1}/_{3}$ to $2^{1}/_{2}$ times normal amounts. This high variability in seasonal rainfall makes it very difficult for the farmer to plan and prepare for the forthcoming season. In the absence of reliable information about the expected rainfall, farmers normally adopt low input agriculture aimed more at reducing risk than at increasing productivity and profitability. Hence, advance information about the likely rainfall during the forthcoming season is an important input that can greatly enhance the ability of the farmers to plan and take advantage of the likely good seasons and minimize risks in the poor ones.

The recent developments in understanding the global climate systems, especially the influence of phenomena like El Nino Southern Oscillation (ENSO), have contributed significantly to greater reliability in predicting the seasonal weather conditions (Ropelewski and Halpert 1987). The accurate prediction of the 1997 El Nino event is a good example of this. A number of global and regional meteorological organizations are now engaged in developing seasonal forecasts using this and other phenomena. Considerable progress has also been made in applying these seasonal climate predictions to agricultural decision-making, especially in Australia and countries in Asia. However, the use of forecasts for agriculture in the ECA region remains underdeveloped. A case study from ICRISAT work in South India is presented here to highlight the extent to which productivity gains can be achieved using forecast-based farming. The approach proposed here is suitable for use in other regions provided reliable forecasts for that region are available.

A case study from southern India

The ICRISAT Production System 9, comprising parts of Andhra Pradesh, Karnataka and Tamil Nadu states of India is a tropical, intermediate-length rainy season area with sorghum/oilseed/pigeonpea interspersed with locally irrigated rice as the major agricultural land use system. The dominant soil of the region is Alfisols, covering 85% of the area in the production system. The mean annual rainfall in the region is between 400 and 900 mm. At Anantapur, minimum, mean and maximum crop season rainfall recorded between 1962-2000 is 137, 401 and 723 mm, respectively. About 25% of the years will have a deficit rainfall while another 25% of the years experience excessive rainfall. The mean yields of both irrigated and dryland crops are very low. The yield of groundnut, a major dryland crop occupying 3.22 m ha, ranges between 0.9 and 1.5 t ha^{-1}.

Farmers traditionally used cropping systems involving drought-tolerant crops like sorghum and millets, and forecasts based on indigenous knowledge to reduce the impact of weather aberrations on agricultural production. However, driven by the need for more cash income, farmers are now forced to replace the traditional cropping systems with those that are more risky but profitable. For example in the Mahaboobnagar and Anantapur districts of Andhra Pradesh, the area under sorghum, millets and other drought-tolerant crops has declined several fold, while the area under drought-sensitive crops like sunflower, maize and cotton have increased considerably (Figure 1). Owing to their low reliability and dependability, use of traditional forecasts byfarmers in planning agricultural activities is also very low.

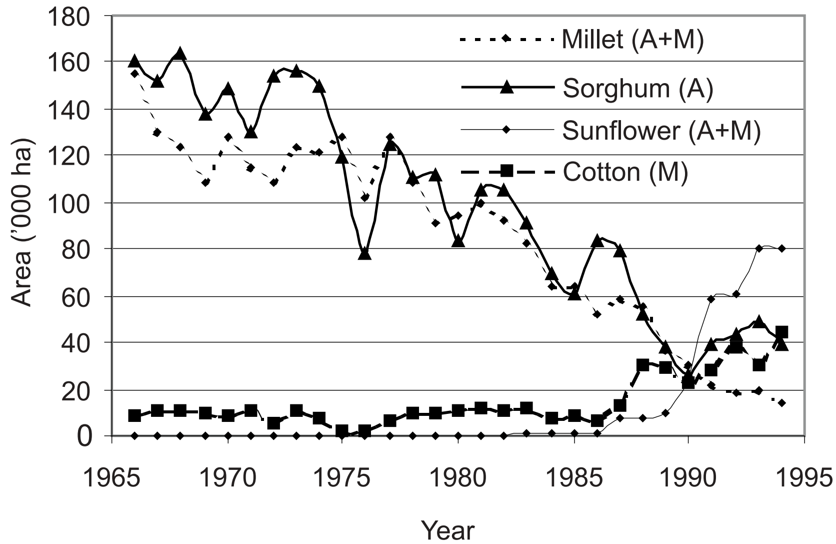

Figure 1. Major changes in the crops grown in Mahaboobnagar and Anantapur districts, Andhra Pradesh, India.

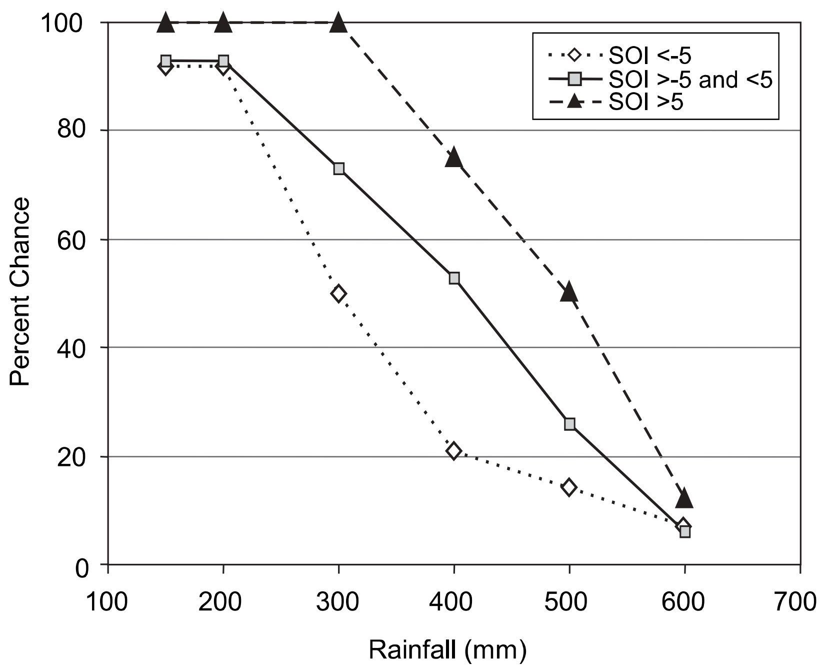

Figure 2. Chance of rainfall at Anantapur during July-September based on SOI phase during April-June.

An analysis of historical rainfall data has indicated a good relationship between the rainfall during the cropping period (July to September) and the Southern Oscillation Index (SOI) during April-June. Crop seasons following a positive SOI tend to be wetter than the ones with negative SOI. For example, at Anantapur, the likelihood of getting > 300 mm rain during the main cropping season, which is essential for a good groundnut crop, was 72% during positive SOI years and 7% during the negative SOI years (Figure 2).

The hindcasts developed using the historical SOI data for 36 years have indicated that 19 of these years followed a positive SOI, 12 followed negative SOI and the rest followed a neutral SOI. Nearly 80% of the wet year and 67% of the dry year hindcasts turned out to be accurate. Using the system simulation model APSIM and the analog year technique, the groundnut productivity under traditional and forecast-based farming was assessed to quantify the potential benefits from the use of seasonal forecasts. Forecast-based farming suggests use of higher groundnut plant population and intercropping with pigeonpea using 1:3 row ratio during wet years and lower plant population and intercropping with pigeonpea in 1:10 row ratio during dry years. The results of the analysis have indicated that the productivity of forecast-based farming was 32% higher in wet years and 14% lower in dry years compared to the farmer practice. The overall gain from forecast-based farming was 19%.

Opportunity in the ECA region

This study has clearly demonstrated the potential benefits that can come form the use of forecasts in the areas receiving reliable seasonal climate forecasts. In the ECA region the most prominent mode of predicting interannual climate variability appears to be ENSO (Stone et al. 1996; Mason and Goddard 2001). The long rains are negatively correlated with ENSO, although the signal is much weaker than that for the short rains (Ogallo 1989). Indeje and Semazzi (2000) have found very high correlations in excess of 0.8 between the eastern Africa “long rains” and the stratospheric quasi-biennial oscillation index for time lags of about 7 months, thus raising new prospects for the predictability of the “long rains”. The other modes of variability of the African climate include Indian Ocean interannual variability, Atlantic SST gradient across the ITCZ, NAO mode and its decadal variability and Continental-Scale Decadal modes. Since 1989, the Drought Monitoring Center at Nairobi has been providing the region with weather and climate advisories. However, their use in agricultural decision-making remains underdeveloped. Climate forecasts are also available from the International Research Institute for Climate Forecasting (IRI), the Queensland Center for Climatic Applications (QCCA), and the European Center for Medium Range Weather Forecasts (ECMRWF), and there is a need to explore the opportunities for forecast-based farming, which has not yet received the attention that it deserves in the region.

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Large-scale assessment of deforestation and land degradation in Western Kenya

Alex Awiti, Markus Walsh and Keith Shepherd

The current land use and land management practices in the Lake Victoria basin are placing unprecedented stress on both natural and managed ecosystems. Consequently, ecosystem structure (species composition) and function (e.g. primary productivity, biogeochemistry, hydrology-infiltration and water retention) are often altered in ways that impair the sustainability of current land use, and limit future land use options.

A combination of remote sensing, diffuse reflectance spectrometry (DRS), isotopic ratio mass spectrometry (IRMS), accurate Global Positioning Systems (GPS) epidemiological approaches for risk assessment, and replicated spatial analogue survey methods have been used to facilitate rapid large-scale assessment of the impact of deforestation and land degradation.

Our results demonstrate that: (1) In the top 20 cm depth, root density in cultivated land had been reduced to 8.7% of the root density in the forest after 60 years. (2) The average litter ($t\ ha^{-1}$) measured in the forest was 9.5 times that measured in cultivated land. (3) Surface and subsurface hydraulic conductivity was significantly higher ($P < 0.0001$) in the forest than in adjacent cultivated land. (4) Root:shoot ratio of maize grown on forest soils was significantly lower ($P < 0.001$) than that of maize grown in soils from cultivated land. (5) Soil fertility and maize productivity decline slowly during the first 20 years after forest conversion, but much more rapidly in the subsequent 40 years after conversion. By 130 years of continuous cultivation, converted forest soils will have lost approximately 92% of their former soil fertility. (6) Land use systems which have been historically dominated by C3 photosynthetic pathway carbon inputs appear to have about 2.5 times higher soil carbon sink potentials and are approximately 15 times less likely to show symptoms of erosion than those historically dominated by C4 carbon inputs.

The pathways of soil fertility decline after forest conversion have been established. We have developed models that enable us to determine threshold levels of vegetation cover for protection of different soil types and slope classes. Our findings provide a fundamental basis for making recommendations on appropriate interventions for land management as well as providing a forum for engaging policymakers to identify appropriate policy responses to mitigate and possibly reverse the current trends in land degradation and deforestation.

A distributed GIS-based soil moisture distribution and routing model

Tammo S Steenhuis, P Gérard-Marchant, Mark S Johnson, and M Todd Walter

Computer simulation models of watershed hydrology are used to examine watershed-scale processes and to evaluate the hydrologic effect of various management scenarios. The use of watershed models is an important tool in planning soil and water conservation practices (SWCPs). The complexity of watershed models is also increasing with recent advances in computer technology, which allow simulation of the myriad conditions and processes that occur in hydrologic systems.

Watershed models can be categorized according to their runoff-generating mechanism, which can be either: (1) infiltration-excess overland flow (Hortonian overland flow), (2) saturation-excess overland flow, or (3) a combination of (1) and (2). Infiltration-excess overland flow is generated when the precipitation rate exceeds the infiltration capacity of the soil or land surface, and can be a dominant process in urbanized or otherwise disturbed areas, as well as in areas that typically receive high intensity precipitation and that have a low permeability crust at the soil surface. Saturation-excess overland flow is generated when the soil becomes saturated to the extent that additional precipitation cannot infiltrate. Saturation-prone areas are primarily those with a high water table and shallow soils that provide little additional storage for water. These saturated areas are a function of the landscape scale and, therefore, can only be modeled with distributed models that preserve the spatial location of each field in the overall landscape. TOPMODEL and the Soil Moisture Distribution and Routing model (SMDR) are two of this type of models. Both models are very similar (Walter et al. 2002). TOPMODEL assumes that the watershed has an underlying water table, while SMDR presumes that there is a hardpan with the same slope as the surface soil. Here we will highlight the SMDR model that was developed by us.

SMDR is a raster GIS-based, physically distributed watershed model that incorporates saturation excess as the primary runoff-generating mechanism (Frankenberger et al. 1999, Kuo et al. 1999). Horizontal representation by SMDR is fully preserved by running the model within the Grass GIS system under Linux. The hydrodynamic properties are divided into small elements, or cells. The geological, topographical and soil hydrodynamic properties are defined at each grid point of the region. Physically-based water balance equations are applied to each grid cell at each time step. The fluxes simulated are shown in Figure 1. Parameters used in SMDR are derived from soil survey and remotely sensed data, and are supplemented with field data where possible. The soil survey data can be applied to as many as four soil layers without modification.

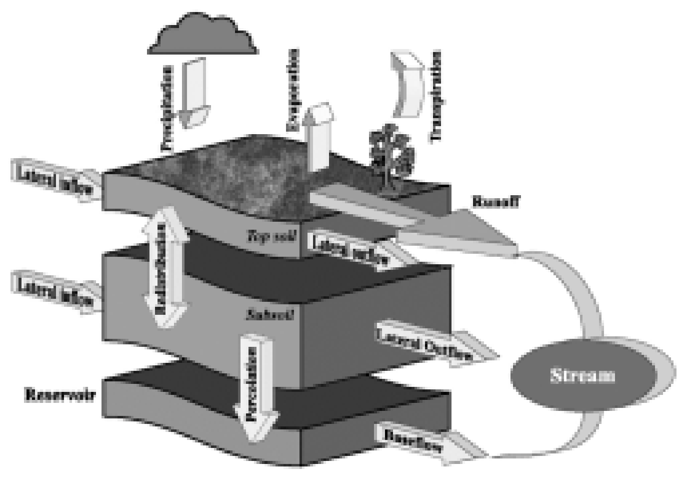

Figure 1. Simulated fluxes in SMDR for each grid cell.

A water balance for each time step is calculated from moisture inputs, subsurface lateral flow, deep percolation, and runoff. Runoff is generated when rainfall exceeds the storage capacity of a grid cell. At the beginning of each time step, precipitation and snowmelt inputs are added to the soil moisture

volume of the soil profile of each grid cell. This volume is then distributed among the layers in proportion to each layer's thickness and water-holding capacity. If micropore storage is satisfied for all layers, the remaining moisture begins filling the soil layers to saturation, beginning with the deepest layer and proceeding upwards to successive layers.

The distributed nature of SMDR permits assessment of a watershed's response to precipitation on both integrated and distributed levels. Integration of surface runoff over the watershed at each time step allows comparison with observed stream flow. Distribution of SMDR results, such as soil moisture content and water table depths, can be evaluated at a grid-cell scale through a variety of analytical methods to compare predicted results with observed values.

Use of the model has demonstrated good results in many parts of the USA including New York, Illinois, Indiana, and Utah. A sample output that indicates the area where most runoff occurs is given in Figure 2 for a watershed in the Catskill Mountains.

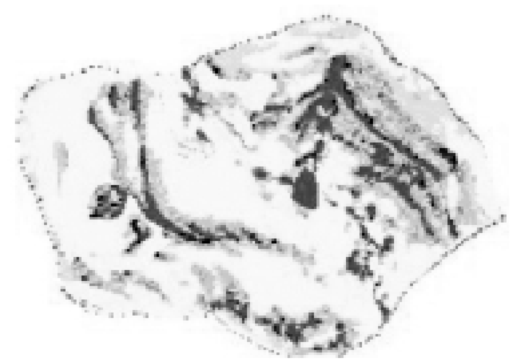

Figure 2. Distribution of runoff in a watershed. High runoff areas have the darkest shades.

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Data reusability issues: experience from a few ICRAF data sets of relevance to the Soil and Water Management Workshop

P Muraya

Introduction

Data collection is an important phase in soil and water management research. During this phase researchers may either be generating new data, or they may be compiling old data for reuse in new applications. Generation of new data is often expensive, and may be unnecessary if old data exist that fit a required purpose. However, such data may not be reusable for the new application for a number of reasons. It could be that the data are inaccessible, either physically or protected by some intellectual property rights. It could also be that the data are not being documented well enough for a new user or the data may be organized in a way that makes it difficult to process them further. This paper addresses this imbalance by identifying database options with increasing chances of reusability. These are presented as case studies that can be easily related with. It is hoped that the data generated today will be more reusable data in future.

Data reusability gradient: what is it?

The data reusability gradient is a representation that shows that there are increased chances that research data will be reusable as the combined levels of commitment, skills and other resources are increased to address some typical data management problems. Figure 1 shows that the data least likely to be reused are not shared with anyone, but kept to oneself. Issues of physical access to data (shown in a light grey shade) dominate the lower echelons of the reusability gradient, while documentation and processing efficiency (shown in deeper grey shades respectively) are higher in the data reusability needs. Most scientific journals now have publicly accessible Internet sites where they archive highly documented data permanently. Clark et al. (2000) in the Ecological Archives is an example of such a data set, and its position in the reusability gradient would be somewhere near the highest end of the documentation spectrum. Between the lowest and highest levels of data reusability, there are identifiable options of reusability, depending on the desired levels of inputs (and therefore problems addressed).

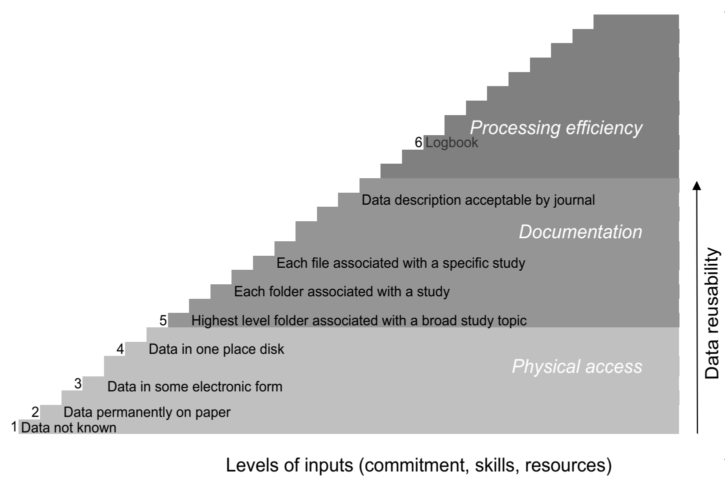

Figure 1. Data reusability gradient.

Case studies

There are 6 cases described in the following section that demonstrate increasing levels of database reusability. We describe the way each database was created, its key physical structure, what

(resources, skills, and commitment) it took to create it, what problems it solves, and finally the main constraints of the database.

1. Unknown database

The first case study is about a database that we like to refer to as unknown. It may or may not exist. Whatever its value, it is not useful to anybody else (other than the originator). When the originator leaves an organization, any hope of the data ever being reusable also ends. This shows that if there is no input (e.g. commitment to place data in a public location) from either field scientists or the research managers, you should not expect high chances of the data being reusable – because it will very easily fall into the 'unknown' category.

2. Some faraway station

This is a database that is well known (unlike the first case study), and comprised entirely of paper and folders. The hard copy has time-tested reliability, but the management, accessibility, and processing of data stored this way does not benefit from advances in information processing. It not possible to share electronically a database maintained entirely in hard paper. There is a lot of work involved to reuse it, including capturing the data with an electronic device and checking for data entry errors.

Table 1. The different types of databases illustrated.

Case No.	Data Source	Main characteristic of the database	Problems addressed by the database	Opportunities for further improvement
1.	Unknown	Unpublished	Unknown	• Impossible to access
2.	Far away Philippines	Paper medium		• Difficult to access remotely • Time consuming data entry + errors
3.	Miscellaneous contributors	Electronic form but different storage media		• Heavy to carry • Data loss due to medium obsolence • Scattered all over the place
4.	ICRAF soils laboratory	Data assembly		• No metadata • Difficult to locate data of interest
5.	Shinyanga data rescue mission	Linking data to metadata		• Insufficient metadata to decide if data is fit for a purpose • Does not add to immediate processing efficiency • Data loss due to software updates
6.	ICRAF's Tree improvement program	Shared data storage for collaborative work		• Not all data types covered, e.g. spatial, derived products • High skill requirements and staff turnover • Database technology-sensitive and open source • High levels of collaboration assumed
7.	?	Next generation data management issues		

3. Multimedia data

This database goes beyond the paper problem expressed in the previous case. The data are well known and archived on both hard paper and recorded in electronic media – different media (5 ¼-inch floppy disk). There is no computer now at ICRAF that can read the 5 ¼-inch floppy disk – implying that data currently recorded on such media are effectively lost. What worsens the problem is that there are so much data in these floppies, stored in different offices, that it would take many person hours to convert them to other modern media – hours that few institutions are ready to spend, thus reducing the chances of the data being reused.

4. ICRAF Soils Laboratory

This is the case of a scientist who had been at ICRAF for nine years and who realised his data legacy needed organizing, particularly as he had inherited a lot of undocumented files from a colleague who had left earlier. He hired help so that he could document the contents of every file, remove duplicates and incorrect versions, and organise them into a set that could be easily managed. The result was a database with 1700 data files carefully organized into over 400 folders and packaged into a single easily portable CD-ROM disk. It had a problem, though – the folder structure was too complicated for anyone else to understand what data files were stored where. Furthermore, there was no direct link between the documentation word processor files and the spreadsheet ones that they described. A newcomer would therefore not be able to reuse the data.

5. Shinyanga data rescue

This database represented 10 years of research conducted at one of ICRAF's research stations, at Shinyanga in Tanzania. The data resided in 4000 files stored on 8 computers and were easily accessed through a local area network. The need to compile an easily accessible database arose when a new research team leader needed to be sure that all data collected were continually available and sensible.

The task of compiling this database was easy, because the resident data technician was well versed with data organization on each computer. There were a total of 31 experiments, all of them well documented. We simply needed to associate each data file with one (or more) of these experiments – a task that would have positioned the resulting database at a high level on the reusability gradient, but it could easily have taken one month to accomplish. Since the task needed to be accomplished in 2 days, it was done by settling to a lower point in the gradient – to associate each folder in the database with the experiments. The 31 experiments are grouped into 7 broad categories. Using the data technician's knowledge of the data organization on each computer a table (i.e. data directory) was built to associate the folders with one or more of the categories. The result was a data bank, fitted on two 650MB compact disks that one could search in very broad terms.

6. ICRAF's tree improvement program

The ICRAF tree improvement program decided to produce an archive of research data and requested the research support unit to produce a highly reusable database using the latest database technology. The output was a stand-alone CD-ROM disk that avoided the multimedia problem highlighted in case 3 and solved in cases 4 and 5. The CD contained only one file, solving the multi-file problem highlighted in cases 4 and 5. The single file was a relational database, designed to hold both the actual raw data generated by the research activities and the detailed documentation for the data, all linked

in an easy-to-browse way – the problem that was partially addressed in case 5. The database was managed using a specially constructed interface called the Logbook Assistant that allowed (1) compiling of the original individual data files into the single database file, (2) browsing the results by research activity (rather than by files and folders), (3) retrieving detailed documentation for each activity, and finally (4) selecting and outputting the raw data in a form ready for further investigation and reuse.

This database does not represent the highest level of possible data reusability. For instance, while the Logbook system has worked well with plot-scale type of data, it was not designed to handle spatial types of data, now commonly used at scales larger than the usual experimental plots and household surveys. Also, the relational database used is complex and one would require specialized skills to fully exploit the system.

Summary

Table 1 summarizes the 6 types of databases illustrated; the 7th one is theoretical. The problems addressed column is blank because they can be deduced from the opportunities column of the previous box. Thus in Case 4, the arrow means 'data easily lost due to media obsoleteness' was solved to produce the ICRAF soils lab database.

Conclusion

This approach of describing data reusability recognizes that one size cannot fit all. That is particularly true of ICRAF; some research sites have better computing facilities than others; some have better communication facilities than others; and some have more access to highly skilled labor than others. The approach is a useful tool to help in self-assessment. It helps you to determine where you are in the data reusability gradient (i.e. which of the examples best match your current situation); where you would like to go (i.e. which database best matches what you would consider reasonable); and finally, what inputs you might require to get there. The set of databases is not exhaustive. There are gaps. We would like to fill them, so that we enlarge the range of data management options available to our researchers.

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Annex 4: Summary Description of Models Demonstrated at the Workshop

PARCHED THIRST model: Introduction and how to get started

OB Mzirai, FB Rwehumbiza, SD Tumbo and N Hatibu

The name of this model (PARCHED-THIRST) stands for Predicting Arable Resource Capture in Hostile Environments During the Harvesting of Incident Rainfall in the Semi-arid Tropics. It is a user-friendly, process-based model that simulates the key processes influencing the performance of rainwater harvesting (RWH) systems. The model represents the result of a collaborative effort involving research teams from the University of Newcastle upon Tyne in UK and Sokoine University of Agriculture in Tanzania. The research effort, which included field trials and experiments in Tanzania as well as model development and testing, was funded by the UK Department for International Development (DFID).

Rainwater harvesting is an umbrella term that describes a range of techniques for collecting, concentrating and conserving water derived from rainfall runoff. Water derived in this way may be supplied to crops or livestock or used for domestic consumption. We are concerned only with RWH systems in which runoff is collected and delivered to a crop without storage other than in the soil within the cropped area. Even with this limitation, many different RWH systems can be recognised across a range of spatial scales. A distinction can be made between:

i) *Micro-catchment or within-field methods,* which involve transfer of water over a short distance (0-50 m), usually by sheet flow;

ii) *Macro-catchment or external catchment methods,* which involve collection of water from a catchment area at a considerable distance from the receiving area, and its transfer by channel flow.

For the purpose of simulation, all RWH systems can be represented as a combination of runoff-producing areas and runoff-receiving areas as shown in Figure 1.

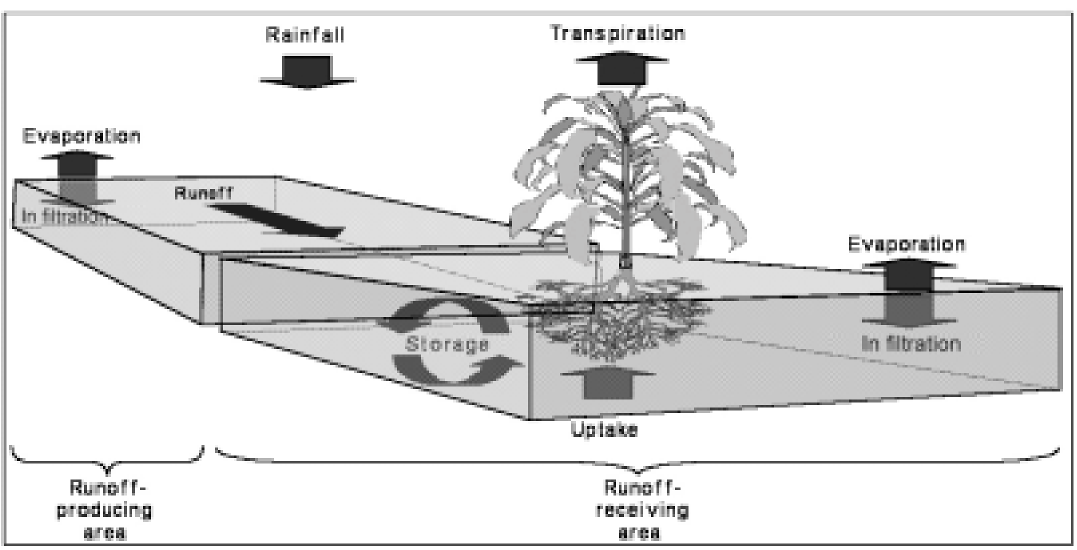

Figure 1. The hydrological components of a conceptual RWH system.

The model is designed to assist agricultural planners and advisers whose aim is to improve cropping systems in dryland environments, where the major factor limiting crop performance is the imbalance between water supply and demand. In seeking improvements, they face difficulties in finding answers to questions such as:

- For a given field, which of the many RWH techniques is going to best match the livelihood strategy of the farmer and what is the optimum configuration of that technique?
- Given a successful technique in one area, how can we identify other areas where the technique might also be successful?

The model therefore should be seen as a tool that helps to identify best-bet RWH system options at any particular site. The model can also be used as a teaching tool, as it has many functions that can be used by students to test various scenarios, from real practical problems to hypothetical situations.

An earlier version of the PARCHED-THIRST model (v1.0) was released in 1996. Users who are familiar with version 1.0 should have no difficulty in switching to this new version (v2.x), which retains much of the appearance of the original as well as all its capabilities, while also including many additional capabilities. New users may require some assistance in understanding the model and exploring its capabilities.

The model is distributed in a stand-alone CD, which has several facilities that can give the user access, depending on his level of understanding of the model. Experienced users can go straight to using the model, through the 'experienced user' tab, whereas new users can go through a setup wizard, and the model has a tutorial and online help. The model does not require the user to have any background in hydrology and/or crop physiology. However, the users must have an understanding that will help to interpret the output from simulation.

The sets of instructions below demonstrate how to create a RWH system; introducing the system to the user, the components of a RWH system, and setting up of system parameters. You will learn how to run the system in order to simulate various crop-soil-weather scenarios.

Getting started

In arid and semi-arid climates the major factor limiting the growth of crops in most years is the imbalance between the demand for water by the atmosphere and the supply from the soil. There is little that can be done to decrease the atmospheric demand but water conservation can increase the amount of water stored in the soil by reducing the proportion of rainfall that runs off the surface. Alternatively, water can be harvested from adjacent areas, thus increasing the amount of water available to the plant (rainwater harvesting). In order to assess whether this type of intervention by farmers is worthwhile, the benefits in terms of crop yield need to be determined over a number of years with different seasonal rainfall patterns. While PTv2.x can be used to simulate rainfed crop growth, the simulation of rainwater harvesting is an integral part of its functionality. The following section takes you through the steps necessary to use PTv2.x to evaluate options for RWH interventions.

Creating a RWH system

A complete RWH system must have both a Catchment Area and a Cropped Area. In PTv2.x these areas are represented by *Profiles*. A profile is assumed to represent a homogeneous area of the

landscape. A profile has properties that define the soil characteristics, the soil surface, the crop to be grown, and any weeds. Each profile is joined to another by a link that specifies the direction of movement of any runoff. Every profile must be linked to at least one other, and at least one profile must be linked to the sink, which represents an undefined destination for runoff lost from the RWH system. Runoff from one profile can only be directed to one other profile, but a profile may receive runoff from any number of profiles.

In PTv2.x, a simulation scenario is called a *System*. A system, which can be thought of as a landscape, is a collection of profiles (each of which has its own properties) with information on the geographical location (including weather data to be used), simulation start dates and crop planting dates. The system can have as many profiles as desired, but the current setting of the model allows only up to 20 profiles. In this tutorial we will create a system with two profiles where profile 2 will be our runoff producing (catchment) area and profile 1 will be our runoff receiving (cropped) area. Profile 2 will be linked to profile 1, which means that runoff collected from profile 2 will flow towards profile 1, which will then be connected to a sink.

APSIM: a soil-crop-management systems simulation platform

John Dimes

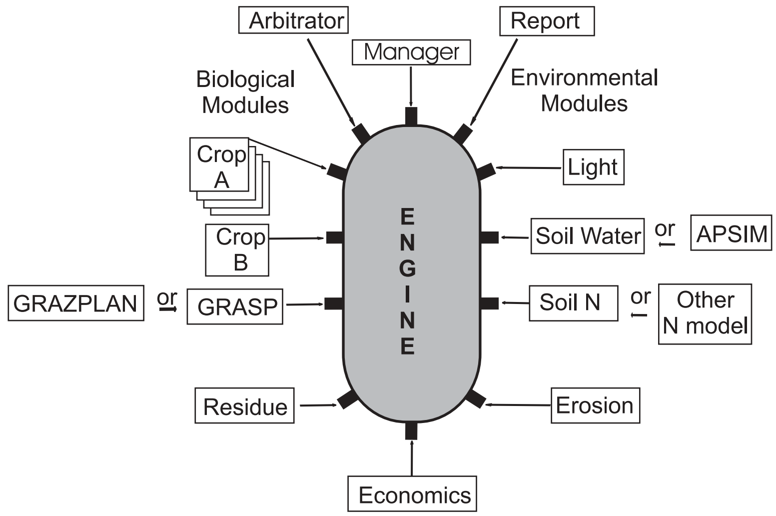

Figure 1. A schematic diagram representing the plug-in, pullout modularity of APSIM, facilitated by standardized protocols across modules for linking into a communications platform called 'the engine'.

The Agricultural Production Systems sIMulator (APSIM) is a modeling framework that provides capabilities via component modules to simulate cropping systems over variable time periods, using available meteorological data (McCown et al. 1996, Keating et al. 2002). Modules can be biological, environmental, managerial or economic and are linked via the APSIM "engine" (Figure 1.). The "engine" is a communication system that passes information between modules according to a standard protocol. The fact that modules are not directly linked with each other allows modules to be plugged in or pulled out of the "engine" depending on the specifications for the simulation task. In this way, the simulation capacity of APSIM is limited only by the availability of modules to simulate the processes peculiar to the system of interest.

APSIM can simulate the growth and yield of a range of crops (Table 1) in response to a variety of management practices, crop mixtures and rotation sequences, including pastures and livestock. This is accomplished in such a way that the soil accrues the effects of the different agricultural practices such as cropping and particular crops, fallowing, residue management and tillage. In this way, APSIM simulates long-term trends in soil productivity due to fertility depletion and erosion. It contains

Table 1. APSIM crop, soil and management modules.

APSIM crop modules	maize, sorghum, millet@, wheat, sugarcane, chickpea, mungbean, soybean, barley, groundnut, canola, cotton*, fababean, lupin, pigeonpea@, mucuna@, hemp, sunflower, lucerne, annual medic, trees, weeds@
APSIM soil and related modules	SoilN, SoilP, Soilwat, SWIM**, Solutes, Residue, Manure@, Erosion, SoilpH#
APSIM management modules	Manager, Fertilize, Irrigate, Accumulate, Operations, Canopy

* by arrangement with CSIRO Cotton Research, Australia
** by arrangement with CSIRO Land & Water, Australia
@ developed in association with ICRISAT and CIMMYT
# developed in association with CSIRO Land & Water

modules that permit the simulation of crop-weed interactions, soil organic matter rundown, nutrient leaching, soil erosion, acidification and soil phosphorus. There is, however, no current capability of dealing directly with effects of salinisation, insects, diseases or biodiversity loss.

APSIM runs under Microsoft Windows 95 to XP and NT4 and assumes that the user has a basic understanding of Windows terminology and operation. Two user interfaces, APSIM-Explorer and APSFRONT, are available to simplify transferring the simulation scenarios defined by the user into the APSIM environment.

APSIM-Explorer requires a high level of knowledge and understanding of APSIM functionality and input parameter and management code syntax and is usually the preserve of experienced modelers. APSFront is a 'user friendly' interface providing a menu-based system for using a subset of the functionality of the APSIM application. This interface is well suited for new users of ASPIM, to learn the process of cropping systems analysis and APSIM capabilities. APSFRONT allows selection of input data (climate, soil, crop, management), output data from modules of interest (e.g. water balance, C, N and P balances, crop growth and yield) management of simulation scenarios (saving, running, retrieving, deleting), error checking (summary of scenario set-up inputs and run time operations) and output analysis via software links for viewing output data in text file, APSIM graphics software (APSVIS, APSIM-OUTLOOK) or forwarding to Microsoft-Excel).

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