PAN-EARTH SUB-SAHARAN AFRICA WORKSHOP REPORT

11-15 SEPTEMBER 1989
SALY, SENEGAL

Co-Sponsored by:
PAN-EARTH PROJECT
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PAN-EARTH/OUA-SAFGRAD/ISRA WORKSHOP
ON THE EFFECTS OF CLIMATE CHANGE
ON AGRICULTURAL AND ECOLOGICAL SYSTEMS IN SUB-SAHARAN AFRICA
11-14 SEPTEMBER 1989
SALY, SENEGAL

SUMMARY REPORT

The PAN-EARTH Sub-Saharan Africa Workshop, convened by the PAN-EARTH Project, OAU/SAFGRAD, and ISRA, was held in Saly, Senegal, from 11-15 September 1989. This workshop focused on the effects of global climate changes on the agriculture and ecology of the countries of sub-Saharan Africa. The workshop participants came from thirteen African countries: Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea-Bissau, Kenya, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. There were also representatives from the PAN-EARTH climate change case studies in Japan and Venezuela, and from the United States.

Major institutions represented at the workshop included: ICRISAT, OAU/SAFGRAD, PAN-EARTH Project, UNDP, UNESCO, and US AID. Funding for the workshop coordination, travel, hotel expenses, and publications was provided by: Rockefeller Brothers Fund, International Development and Research Centre/Canada, Ford Foundation, U.S. Agency for International Development, and U.S. Environmental Protection Agency.

Dr. Joseph Menyonga, OAU/SAFGRAD International Coordinator, delivered welcoming remarks. The workshop was officially opened by Cheikh Abdoul Khadre Cissoko, Minister of Rural Development for Senegal, who welcomed the participants in the name of President Abdou Diouf of Senegal. The Minister expressed his interest in and support for establishing a research network on the important effects of climate change on the fragile ecological and agricultural systems of the sub-Saharan countries, both from global warming from the greenhouse effect and from nuclear winter following nuclear war.

During the first day's sessions, climatologists discussed the functions of general circulation models, which model global climate processes. The potential use of these models and other methodologies for defining future climate change scenarios for sub-Saharan Africa was explored. Various models were compared and limitations were noted. The causes of greenhouse-effect climate change, from emissions of CO₂ (carbon dioxide), CH₄ (methane), and CFCs (chlorofluorocarbons), were discussed, and questions brought out important information about various sources of these emissions: vehicles; use of coal, oil, and other fossil fuels; and burning of firewood without reforestation to compensate. Many of these sources are growing parts of the sub-Saharan African economy, both industrial and community-based, especially because of population growth. Scenarios based on smoke and dust production from nuclear
weapons explosions, leading to nuclear winter, were also discussed. The climatologists concluded that for sub-Saharan Africa, changes in precipitation patterns and amounts are expected to have more important consequences than are temperature changes.

Important issues for determining biological effects, both for ecological and agricultural systems, were examined. It was concluded by several speakers that while precise climatological data are still uncertain, the range of future climate change is fairly well determined. The consensus emerged that identification and analysis of biological systems vulnerable to climate change effects within this expected range cannot be delayed until all climatological figures are exact, as negative effects on biological systems translate quickly into harmful effects on human society, especially in economies that are not robust.

Dr. Taye Bezuneh, Director of Research, OAU/SAFGRAD, presented background information on the PAN-EARTH Project and its connections with OAU/SAFGRAD. He detailed the existing crop networks in sub-Saharan Africa and explained the interconnections with the proposed PAN-EARTH Sub-Saharan Africa Collaborative Research Network. Dr. Mark Harwell, Cornell University, International Coordinator of the PAN-EARTH Project, presented an overview of the Project, as well as the scientific issues and methodologies involved. The PAN-EARTH studies are centered around sustainability issues for ecology and agriculture, blending the efforts of scientists from these disciplines with climatological information to integrate methodologies and look at systems holistically.

The second day's sessions gave an opportunity for African scientists to present papers detailing valuable information on sub-Saharan ecology and agriculture and possible effects of global climate change from greenhouse gases and from nuclear winter, much of which was based on research previously done for drought effects. Presented papers covered a wide variety of topics, such as effects of climate change on: crops in the Sudano-Sahelian zone, forest ecosystems in Côte d'Ivoire, coastal systems of Benin and Togo, Sahelian ecology, human behavior, and crop production in north Guinean and Sudan savanna zones. Other topics covered included relating climate change effects in Kenya to El Niño events and the effects of human activities on the climate of Togo. Questions from the participants led to interesting discussions of these research topics and plans for further exchange of such relevant information as will assist in the analyses of climate change effects.

The third day's sessions began with presentations on the progress of the PAN-EARTH case studies already established in Venezuela, Japan, and China. Then a simulation model for grasslands was presented, and data needs were detailed. A pastoral model for semi-nomadic livestock in eastern Africa was also presented. The crop simulation models developed for the IBSNAT/DSSAT program, funded by US AID, were presented in detail, and the remainder of the day was spent demonstrating use of and discussing data acquisition for these important models.
The participants divided into three working groups for the fourth day, examining in detail plans for analyzing ecological, agricultural, and climatological effects. The groups were charged with developing climatological data needs and lists of agricultural and ecological sites suitable for research on climate change effects. Coordinators for each crop type were designated and coordinators and contact scientists were listed for each ecological site. Reports from these working groups were presented on the final day, on potential climatological scenarios, agricultural and ecological sites, and key personnel in many countries and institutions.

The assembled scientists unanimously voted to establish the PAN-EARTH SUB-SAHARAN AFRICA COLLABORATIVE RESEARCH NETWORK, coordinated by OAU/SAFGRAD in cooperation with the international PAN-EARTH Project headquartered at Cornell University, USA. The assembled participants adopted the following as a part of their Final Recommendations, presented on behalf of the participants by Dr. R.A.D. Jones, National Agricultural Research Coordinator, Sierra Leone:

- the formal establishment of a network of scientific activities among African scientists and international collaborators to identify the vulnerable systems of concern in sub-Saharan Africa and to conduct assessments of climate change and its impacts on humans and the environment;

- the improvement of agricultural, ecological, and climatological data bases and research activities in national, regional, and international institutes and organizations;

- that the PAN-EARTH SUB-SAHARAN AFRICA COLLABORATIVE RESEARCH NETWORK affiliates provide logistical and other support to these activities, insofar as possible;

- that existing training programs be strengthened and new training programs be developed, especially for collecting and analyzing data and conducting effects assessments;

- that a Pan-Africa conference be convened on the topics of climate change, effects on humans and the environment, and policy implications, responses, and planning strategies for governments in the region; and

- that sub-Saharan governments, the World Bank, African financial institutions, and the donor community recognize the seriousness of the potential consequences in long-term development projects and provide support with whatever financial resources that can be brought to bear on these critical issues.

In addition, a number of specific scientific recommendations, included in the Working Group Reports, was adopted by the participants.

The workshop Final Communiqué, presented by Dr. Paul Nchoji Nkwi, Scientific Technical Advisor, Ministry of Higher Education, Computer Services, and Scientific Research, Cameroon, affirmed the establishment of the PAN-EARTH SUB-SAHARAN AFRICA COLLABORATIVE RESEARCH NETWORK and was adopted by the participants.

The workshop was adjourned by Dr. Messan Gnininvi, Solar Energy Laboratory, Lomé, Togo.
RAPPORT SOMMAIRE
ATELIER PAN-EARTH/OUA SAFGRAD/ISRA
EFFETS DES CHANGEMENTS CLIMATIQUES
SUR LES SYSTEMES AGRICOLES ET ECOLOGIQUES
EN AFRIQUE SUB-SAHARIENNE
11 - 14 SEPTEMBRE 1989
SALY, SENEGAL


Les principales institutions représentées à l'atelier sont : ICRISAT, OUA/SAFGRAD, Projet PAN-EARTH, PNUD, UNESCO et USAID. Le financement pour la coordination de l'atelier, les déplacements, les frais d'hôtel et de publication a été assuré par le Centre de Recherche pour le Développement International/Canada, la Fondation Ford, le Fonds Rockefeller Brothers, l'Agence des États-Unis pour le Développement International et l'Agence des États-Unis pour la Protection de l'Environnement.

Dr. Joseph Menyonga, Coordinateur International de l'OUA/SAFGRAD a souhaité la bienvenue aux participants. L'atelier a été officiellement ouvert par Mr. Cheikh Cissoko, Ministre Sénégalais du Développement Rural, qui a souhaité la bienvenue aux participants au nom du Président Abdou Diouf du Sénégal. Le Ministre a exprimé son intérêt et son soutien à l'établissement d'un réseau de recherche sur les effets importants des variations climatiques sur les systèmes écologiques et agricoles fragiles des pays d'Afrique Sub-Saharienne, variations résultant du réchauffement du globe du fait de l'effet de serre et de l'hiver nucléaire à la suite de la guerre nucléaire.

Durant les sessions du premier jour, les climatologues ont examiné les fonctions des modèles de circulation générale qui faisaient les processus climatiques du globe. L'utilisation potentielle de ces modèles et d'autres technologies pour la définition de scénarios des variations climatiques futures en Afrique Sub-Saharienne a été explorée. Divers modèles ont été comparés et les limitations ont été notées. Les causes des variations climatiques d'effet de serre provenant d'émission de CO2 (dioxyde de carbone), CH4 (métane) et CFC (chlordifluorocarbures) ont été discutées et les questions ont
amené d'importantes informations concernant les diverses sources de ces émissions : véhicules, utilisations du charbon, du pétrole et autres combustibles fossiles et brulis de bois de chauffe sans reboisement pour compensation. Beaucoup de ces sources constituent une portion croissante de l'économie d'Afrique Sub-Saharienne aussi bien industrielle que communautaire, particulièrement à cause de la croissance démographique. Des scénarios basés sur la production de fumée et de poussière due aux explosions d'armes nucléaires entrainant l'hiver nucléaire ont également été discutés. Les climatologues ont conclu que pour l'Afrique Sub-Saharienne, les variations des régimes et des quantités, de pluies auraient des conséquences plus importantes que celles des variations de température.

D'importantes questions concernant la détermination des effets biologiques pour les systèmes écologiques et agricoles ont été examinées. Plusieurs intervenants ont conclu que si les données climatologiques sont encore incertaines, la gamme des futures variations climatiques est par contre relativement bien déterminée. Un consensus s'est dégagé selon lequel l'identification et l'analyse des systèmes biologiques vulnérables aux effets des variations climatiques dans cette gamme envisagée ne peuvent être retardées jusqu'à ce que les chiffres climatologiques soient exacts, dans la mesure où les effets négatifs sur les systèmes biologiques se transforment rapidement en effets nuisibles sur la société humaine. particulièrement dans des économies qui ne sont pas robustes.

Dr Taye Bezuneh, Directeur de la Recherche de l'OUA/SAFGRAD a exposé l'histoire du projet PAN-EARTH et ses liens avec l'OUA/SAFGRAD. Il a présenté en détail les réseaux existants de recherche sur les cultures et expliqué les interconnections avec le projet de Réseau PAN-EARTH de Recherche Coopérative en Afrique Sub-Saharienne. Dr Mark Harwell, de l'Université de Cornell, Coordinateur International du Projet PAN-EARTH a présenté un aperçu du Projet ainsi que les questions scientifiques et les méthodologies en jeu. Les études de PAN-EARTH sont centrées sur la viabilité de l'écologie et de l'agriculture et associent les efforts des chercheurs de ces disciplines aux informations climatologiques pour intégrer les méthodologies et considérer les systèmes d'une manière globale.

Les sessions du deuxième jour ont donné aux chercheurs africains l'occasion de présenter des communications détaillant de précieuses informations sur l'écologie et l'agriculture Sub-Saharienne ainsi que sur les effets possibles des changements climatiques du globe. La plupart de ces informations étaient basées sur la recherche antérieurement menée sur les effets de la sécheresse. Les communications présentées couvraient une large gamme de sujets tels que les effets des variations climatiques
sur les cultures en zone Soudano-Sahélienne, les écosystèmes forestiers de Côte d'Ivoire, les systèmes cotiers du Bénin et du Togo, l'écologie Sahélienne, le comportement humain, et la production agricole dans les zones de Savane Nord Guinéenne et Soudanienne. D'autres sujets comprenaient la relation des effets des changements climatiques au Kenya avec les événements d'El Nino et les effets des activités humaines sur le climat du Togo. Les questions posées par les participants ont suscité des débats intéressants autour de ces thèmes de recherche ainsi que des projets d'échange ultérieur d'informations utiles contribuant à l'analyse des effets des changements climatiques.

Les sessions de la troisième journée ont commencé par la présentation de l'état d'avancement des études de cas de PanEarth déjà initiées au Venezuela, au Japon et en Chine. Un modèle de simulation a ensuite été présenté et les besoins en données ont été détaillés. Un modèle pastoral pour l'élevage semi-nomade en Afrique Orientale a aussi été présenté. Les modèles de simulation agricole mis au point pour le programme IBSNAT/DSSAT financé par l'USAID ont été détaillés et le reste de la journée a été consacré à la démonstration de l'utilisation des données et à l'examen de l'acquisition de ces données pour ces modèles essentiels.

Les participants se sont répartis en trois groupes de travail pour la quatrième journée afin d'examiner en détail les plans d'analyse des effets écologiques agricoles et climatologiques. Les groupes ont été chargés de déterminer les besoins en données climatologiques et d'établir des listes des sites agricoles et écologiques appropriés pour la recherche sur les effets des changements climatiques. Des coordinateurs pour chaque type de culture ont été désignés et des chercheurs servant de contact ont été choisis pour chaque site écologique. Les rapports de ces groupes de travail ont été présentés le dernier jour et portaient sur les scénarios climatiques potentiels, les sites agricoles et écologiques et le personnel clé dans nombre de pays et d'institutions.

L'assemblée des chercheurs a proposé à l'unanimité l'établissement d'un RESEAU PAN-EARTH DE RECHERCHE COOPERATIVE EN AFRIQUE SUB-SAHARIENNE, coordonné par l'OUA/SAFGRAD en collaboration avec le Projet International PAN-EARTH dont le siège se trouve à l'Université de Cornell, USA. Les participants ont également adopté ce qui suit dans le cadre de leurs recommendations finales présentées au nom des participants par Dr. R.A.D. Jones, Coordinateur National de la Recherche Agricole de Sierra Léone.

- Création officielle d'un réseau d'activités scientifiques entre les chercheurs africains et les collaborateurs internationaux pour identifier les systèmes vulnérables préoccupant l'Afrique Sub-Saharienne et déterminer les changements climatiques et leurs impacts sur les hommes et l'environnement.
- Amélioration des bases de données agricoles, écologiques et climatologiques et des acitivités de recherche des instituts et organismes nationaux, régionaux et internationaux.

- Soutien logistique et autre du membres du RESEAU PAN-EARTH DE RECHERCHE COOPERATIVE EN AFRIQUE SUB-SAHARIENNE à ces activités, dans la mesure du possible.

- Renforcement des programmes de formation existants et creation de nouveaux programmes de formation particulièrement pour la collecte et l'analyse des données et pour l'évaluation des effets.

- Organisation d'une Conférence Pan-Africaine sur les thèmes des changements climatiques, des effets sur les hommes et l'environnement ainsi que des implications politiques, des réponses et des stratégies de planification pour les gouvernements de la région et

- reconnaissance par les gouvernements sub-sahariens, la Banque Mondiale, les institutions financières africaines et la communauté des donateurs de la gravité des conséquences potentielles dans les projets de développement de long terme et soutien par toutes ressources financières pouvant être mobilisées pour résoudre ces questions cruciales.

En outre, un certain nombre de recommandations scientifiques spécifiques incluses dans les rapports des groupes de travail ont été adoptées par les participants.

Le communiqué Final de l'Atelier présenté par Dr. Paul Nchoji Nkwi, Conseiller Technique Scientifique du Ministère de l'Enseignement Supérieur, de l'Informatique et de la recherche Scientifique du Cameroun a confirmé la création du RESEAU PAN-EARTH DE RECHERCHE COOPERATIVE EN AFRIQUE SUB-SAHARIENNE et a été adopté par les participants. L'atelier a été clos par Dr Messan Gnininvi du Laboratoire d'Energie Solaire de Lomé, Togo.
WORKSHOP ANNOUNCEMENT

An announcement of the formation of this workshop was prepared by Drs. Taye Bezuneh and Mark Harwell. It was mailed to many invitees throughout sub-Saharan Africa. The text of this announcement is presented below, explaining the background of the PAN-EARTH Sub-Saharan Africa Case Study.

INTRODUCTION

Human activities on Earth have continued to bring about critical global environment change; a case in point is the deterioration of the African environment. Environmental changes have already had dramatic effect in Africa on the sustainability of its agricultural and ecological systems. Scientific understanding of the causes requires a multi-disciplinary research approach across a variety of scales from local to continental and a diversity of systems, including atmospheric, ecological, agricultural, and social.

The PAN-EARTH Project (Predictive Assessment Network for Ecological and Agricultural Responses to Human Activities) focuses on global environmental issues, with particular attention to climate change and stratospheric ozone depletion. PAN-EARTH is coordinated by Cornell University (USA) at a global level and by OAU/STRC-SAFGRAD in sub-Saharan Africa. In a series of national- and regional-level case studies, PAN-EARTH atmospheric scientists provide detailed scenarios of regional climate change based upon the output from sophisticated general circulation models (GCMs) as applied to selected case studies. PAN-EARTH biological scientists use suitable analytical approaches to evaluate, from a range of physical scenarios, potential effects on ecological and agricultural systems. These approaches include historical analogues, statistical models, physiological data, simulation models, and expert judgment. The research network cooperators will also perform broad ranges of sensitivity analyses of the climate, ecological, and agricultural models, adapted for each case country, to identify uncertainties and to measure the range of effects that could occur. Data acquisition, model calibration, computer simulations, and quantitative analyses are being conducted primarily by scientists located in the case study countries, with all necessary technical assistance by PAN-EARTH scientists. The PAN-EARTH Project research studies are currently underway in China, Japan, Venezuela, and sub-Saharan Africa.

In order to comprehend the complexities of food production, another major thrust of this project is to assist African scientists and institutions in developing appropriate agricultural models based primarily on the US AID-funded IBSNAT Project, which has produced generic crop models for some of the world’s important crops: maize, sorghum, soybean, wheat, etc. Furthermore, a variety of ecological models will be utilized where available; additionally, the range of ecosystems in sub-Saharan Africa, including the semi-arid region (sudano-sahelian zone, northern Guinea savanna), sub-humid, and humid coastal zones would be analyzed using statistical models and expert judgement. Effects
on pasture land and livestock, locust and other pest outbreaks, hydrology, desertification, and interaction with human exploitation in the region will each receive appropriate attention.

OBJECTIVES OF THE AFRICA CASE STUDY NETWORK

The central objective of the network to be initiated in sub-Saharan Africa would be to characterize the vulnerability of African nations to global environmental change, and to ascertain its critical importance on sustainable development in the region. Some of the salient objectives of the network are:

• to orient scientists and institutions in sub-Saharan Africa to the apparent global climatic changes, as they affect the sustainability of the different agricultural and ecological systems in Africa, through case study analyses that would be initiated in various countries of the region;

• to improve scientific capabilities of scientists and institutions of the region in order to make analysis and characterization of the long-term climate data base available and relate such findings to apparent causes of the African agrarian crises and ecological deteriorations;

• to facilitate the exchange of technical information among African countries on the development and application of crop production models;

• to study the effects of plausible climate change scenarios on the productivity and sustainability of agricultural and ecological systems; and

• through extensive sensitivity analyses, to identify the most important climatic change with agricultural and ecological effects in Africa, so that climate modelers can redirect research to reduce uncertainties about those critical factors.

The technical workshop of African and PAN-EARTH scientists in physical, agricultural, ecological disciplines is scheduled for 11-14 September 1989, at Saly, Senegal, to discuss the effects of global climatic changes on the sustainability of agricultural and ecological systems. At this workshop, specific country level case study projects would also be initiated.

SPECIFIC OBJECTIVES OF THIS WORKSHOP

The specific objectives of the Sub-Saharan Africa Workshop would include:

• initiating the Africa Case Study analyses;

• testing physical/biological interface methodologies; and

• planning and coordinating future case study activities.

Initiate Africa Case Study Analyses

The Sub-Saharan Africa Workshop will accomplish these specific activities:

a. Specify the physical scenarios for case study analyses: These climate change scenarios will primarily be based on general circulation model (GCM) output of statistical, biological, and climatic data specific to grid areas in sub-Saharan Africa. These model outputs will be based on simulations at the Lawrence Livermore National Laboratories and elsewhere. Scenarios will be presented for greenhouse climate change (doubled CO₂ effective concentrations) and for nuclear winter-caused scenarios (using the
Bangkok scenarios). Each scenario will be modified by taking GCM-level grid outputs and altering them collaboratively by PAN-EARTH (detailed in the Beijing [China] Workshop Report). Temperature, precipitation, and other physical changes will be agreed upon at the Sub-Saharan Africa Workshop. In addition, participants will consider changes in UV-B radiation from depletion of the stratospheric ozone layer.

b. Identify and select specific agricultural, meteorological, and ecological systems of sub-Saharan Africa for study of effects of climate change: Criteria for selections are: importance to humans; availability of data bases and scientific expertise; representativeness of the system for climatic zone and ecological importance; and comparability with other PAN-EARTH case studies. Examples include specific rice, wheat, peanut, sorghum, millet, maize, and cassava systems; plus ecological systems of savanna, tropical rain forest, and mangroves. Livestock systems will also be specified.

c. Implement important agricultural models on computers: PAN-EARTH scientists will bring available PC-based crop models for most of the crops listed above. PAN-EARTH will assist African scientists in calibration and use of the crop models.

d. Identify existing data bases on climate and selected crop/livestock/ecological systems. African scientists will identify data bases that may be used to calibrate crop models and to conduct other analyses after the workshop. The specific types of data needed will be agreed upon.

e. Investigate the effects of both natural and human-managed ecosystems upon two major regions of Africa:
   • Savannas (Sahel, Sudan and Guinea)-special attention to the areas with nomadic activities and those that are fallow and cultivated, e.g. used for growing crops or grazing livestock.
   • Humid coastal zones/tropical rain forests, with increasing changes to plantation agriculture, e.g. coffee, cocoa, palm oil, bananas.

Test Physical/Biological Interface Methodologies

At the Sub-Saharan Africa Workshop, methodology development will continue as a follow-up of the previous PAN-EARTH workshops. The focus will be on developing methods to progress from large-scale scenarios to the specific study sites in Africa.

Plan Future PAN-EARTH Africa Case Study Activities

Specific case studies will involve the following countries: Benin, Burkina Faso, Cameroon and Togo. Other countries considering participation in the case study activities are: Nigeria, Congo, Niger, Côte d'Ivoire, Senegal, Zaire, Kenya, Ethiopia, Botswana, Zambia, and Tanzania. During the workshop, participants will agree on responsibilities for such specific post-workshop activities as: data acquisition, model calibration, effects assessments, meetings, fund-raising, and report preparation. The Africa Case Study activities may promote future collaborative research with existing regional and international research institutions such as: ICRISAT, ILCA,
ORSTOM, CIRAD, WARDA, and AGRHYMET.

PROJECT TECHNICAL SUPPORT

The Global Environment Program of Cornell University coordinates the PAN-EARTH Project case studies. It facilitates the support of world-renowned physical scientists for the analysis of critical climate data. Technical support is provided by the Lawrence Livermore National Laboratory, the Los Alamos National Laboratory, the National Center for Atmospheric Research, CSIRO-Australia, the Canadian and the USSR Academies of Sciences, as well as from various research institutions of Canada, USA, Europe, China, and Africa. The IBSNAT Project, funded by US AID, provides the primary support for developing the agricultural models. Generic crop models for most important food grains have already been developed by IBSNAT.

FINANCIAL REQUIREMENTS

It is expected that at least two case studies would be established at each major ecological zone (Sahel, Sudan and Guinea Savannas, humid Eastern African Highlands and Southern African Region). Each of the case studies requires financial support to undertake short-term training for climatic and drop data analyses and to assemble ecological data. Under the technical supervision of the Director of Research, a coordinator would be based at OAU/STRC-SAFGRAD to monitor the implementation of the case studies.
AGENDA

MONDAY, 11 SEPTEMBER 1989

Registration

OPENING SESSION
Chairman: Director General, Institut Sénégalaise de Recherches Agricoles (ISRA)
Rapporteurs: T. Bezuneh and C. Harwell

Remarks
J.M. Menyonga
International Coordinator, OAU/STRC SAFGRAD

Objectives of Workshop
M.A. Harwell
International Coordinator, PAN-EARTH Project

Formal Opening of the Workshop
Cheikh Abdoul Khadre Cissoko
Minister of Rural Development, Republic of Senegal

MONDAY MORNING SESSION
Chairman: M.A. Harwell
Rapporteur: M.V.K. Sivakumar

Global Change and Nuclear Winter: Co-Development of Model Analysis
R. Turco
University of California, Los Angeles

Theoretical Background of General Circulation Models
T. Ackerman
Pennsylvania State University

GCM Greenhouse Warming Scenarios for Africa
A. Robock
University of Maryland

MONDAY AFTERNOON SESSION
Chairman: M. Acevedo
Rapporteurs: M. Traoré and C. Harwell

Biological Effects of Global Climate Change
W. Cropper
University of Florida

M. Acevedo
University of the Andes

Discussion

PAN-EARTH Collaborative Research Networks: African Case Studies to Enhance the
Development of Sustainable Agriculture
T. Bezuneh
Director of Research, OAU/STRC SAFGRAD
TUESDAY, 12 SEPTEMBER 1989

TUESDAY MORNING SESSION
Chairman: T. Bezuneh
Rapporteur: J.J. Owonubi

The Effects of Climate Change on the Production of Sorghum and Millet in the Sudano-Sahelian Zone of West Africa
M. Traoré

The Effects of Climate Change on Forest Ecosystems with Particular Reference to Cultivation of Tree Crops in Côte d’Ivoire
Y. Sangare

Climate Variabilities: Teleconnections in Kenya as an Early Warning System
L.N. Naju and J. Odak (presented by J. Odak)

Effects of Climate Changes on the Sahelian Ecology
E. Bonkoungou

Effects of Climate Change on the Coastal Ecosystems of Benin and Togo
N. Aho

Climatic Changes and Crop Production Patterns in the Sudano-Sahelian Zone
M.V.K. Sivakumar

TUESDAY AFTERNOON SESSION
Chairman: P. Nkwi
Rapporteurs: D.M. Osafo and C. Harwell

Climatic Change and Human Behavior
P. Nkwi

Overview of Climatic Change and Patterns of Crop Production in the Northern Guinea and Sudan Savanna Zones
J.J. Owonubi

An Example of the Effects of Human Activities on the Togolese Environment: Coastal Erosion
K. Koulekey

The Effects of Climate Change on the Production of Millet
M. Diagne

Division into working groups:

Group 1: Climatology
Chairman: R. Turco
Co-Chairman: J.J. Owonubi
Rapporteur: T. Ackerman

Group 2: Ecological Effects
Chairman: M. Acevedo
Co-Chairman: E. Bonkoungou
Rapporteur: M. Coughenour
Group 3: Agricultural Effects
   Chairman: G. Hoogenboom
   Co-Chairman: T. Bezuneh
   Rapporteur: C. Harwell

WEDNESDAY, 13 SEPTEMBER 1989

WEDNESDAY MORNING SESSION
Chairman: M. Harwell
Rapporteur: C. Harwell

Overview of other PAN-EARTH Case Studies
Venezuela
   M. Acevedo
   University of the Andes

Japan
   T. Urabe
   Nagoya University

China
   M. Harwell
   Cornell University

Agricultural and Ecological Models Discussion
   Grasslands and pastoral models
   M. Coughenour
   Colorado State University

IBSNAT/DSSAT models
   G. Hoogenboom
   University of Florida

Modeling Demonstration

WEDNESDAY AFTERNOON SESSION

Modeling Demonstration and Training Session

THURSDAY, 14 SEPTEMBER 1989

WORKING GROUPS ALL DAY

FRIDAY, 15 SEPTEMBER 1989

FRIDAY MORNING SESSION
Chairman: M.K. Gnininvi
Rapporteur: C. Harwell

Presentation of working group reports

CLOSING SESSION AND ADJOURNMENT
PAN-EARTH SUB-SAHARAN AFRICA WORKSHOP MINUTES

Monday, 11 September 1989

WELCOMING REMARKS
Dr. Joseph Menyonga, SAFGRAD

Welcoming remarks were delivered to the participants by SAFGRAD International Coordinator, Dr. Joseph Menyonga. He expressed thanks to the local organizing committee and to ISRA. There are 26 member countries in SAFGRAD, which was set up in 1977, to work with international research centers on problems such as severe droughts, storms, and floods; SAFGRAD also focuses on increasing productivity from increased rainfall. Dr. Menyonga stated that many are not aware of the long-term impacts of climate change; African scientists must be sensitized so they can make the public aware of the problems of sustainable development. Dr. Menyonga explained the PAN-EARTH Project name and background (see section Workshop Announcement, above).

Dr. Menyonga related that Dr. Mark Harwell, PAN-EARTH Project International Coordinator, had recently presented information on climate changes and potential effects at a meeting held in Burkina Faso in April 1989, where many of the crop networks were represented. At that meeting, Dr. Harwell discussed the Africa Case Study objectives and detailed how this workshop in Senegal will provide the tools and information to be more prepared to cope with the effects of climate change. Dr. Menyonga concluded by stating that by the end of this workshop, he hoped the participants would adopt a realistic set of objectives subsequently to be adopted by their member institutions. He noted that financial assistance for this workshop was received from the Rockefeller Brothers Fund, Ford Foundation, US Agency for International Development, US Environmental Protection Agency, International Development and Research Centre/Canada, and from other institutions and governments sponsoring individual participants.

A simultaneous translation into French was provided throughout the workshop for French-speaking participants.

Dr. Mark Harwell, PAN-EARTH Project

Dr. Mark Harwell offered special thanks to Drs. Menyonga and Bezuneh of SAFGRAD, also to the Rockefeller Brothers Fund. Dr. Harwell discussed the background of this Sub-Saharan Africa Workshop and the components of the PAN-EARTH Project (see section Workshop Announcement, above; also see Figures 1, 2). This workshop is focusing on global climate change and nuclear winter and the effects on various countries in sub-Saharan Africa. The object is to characterize as best as possible how climate will change in this region, associated with human activities. Once the relevant changes have been identified, the Case Study scientists will look at effects. Models have been brought to this workshop, and hands-on training sessions will be conducted here and the models will be retained by the participating African scientists. Another objective of this workshop is to advance the science of examining stressed

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1Prepared by C. Harwell based on reports from session rapporteurs.
Figure 1

OBJECTIVES OF PAN-EARTH CASE STUDIES

TO CHARACTERIZE VULNERABILITY OF COUNTRIES TO GLOBAL ENVIRONMENTAL CHANGE

- study effects of climate change scenarios on productivity and sustainability of ecological and agricultural systems

- advance awareness of scientists and institutions about climate change

- advance scientific capabilities in country to assess effects:
  - long-term data bases
  - ecological and agricultural models

- identify critical physical factors, as input to climate modelers
Figure 2

OBJECTIVES OF PAN-EARTH WORKSHOP

- specify physical scenarios of climate change using GCM outputs specific to region

- implement ecological and agricultural models on computers in country

- identify specific agricultural and ecological systems to study, based on climatic zones

- identify existing data bases on:
  - climate
  - ecosystems
  - crop systems
  - livestock systems

- initiate model calibration and use of other methodologies for effects assessments

- establish assessment responsibilities, schedules, products
environmental and societal systems. The workshop will identify specific research activities by African scientists as part of the PAN-EARTH Project; the participants will provide assessments of vulnerable systems and potential effects, and will begin the process of planning for dealing with these effects (Figure 3).

Dr. Harwell was questioned as to what extent developing countries have contributed to climate change; he replied that the contribution varies with the particular gas produced. Carbon dioxide (CO₂), a major contributor to global climate change, is produced from various sources: automobile exhaust, burning of firewood, and consumption of oil and coal. A major problem is not the burning or use of wood per se, but the problem of deforestation: not replanting to replace the wood that is used for fuel. Looking at all developing countries, including those in Latin America and Africa, and including China and India, the combined total contribution is about the same as the total for developed countries; however, per capita consumption is much higher in the developed countries. A problem is that energy usage is more rapidly increasing in the developing countries than in the developed, primarily because of population increases. The rates of population growth are exceptionally high in Africa. China is greatly increasing consumption of fossil fuels (especially coal) to increase living standards there. Dr. Richard Turco added that the contribution of African nations to global climate change from greenhouse gases is very roughly in proportion to their fraction of population in the developing world, including the population of China and India in the count.

There is a lot of uncertainty about the source terms of gases, how they will lead to climate change, where and how fast the physical stresses will be felt, and how these physical stresses translate into biological effects. Dr. Harwell stressed that there will always be uncertainties about some of these issues, but there is a substantial amount now known. He urged the participants to move forward to evaluate as much as possible now: to inform scientists, to identify future research, to determine how to adapt to inevitable changes, and to determine the range of future effects in order to develop the least harmful policies possible.

In China, the PAN-EARTH Project is actively involved with government units dealing with sustainable development; for the Africa Case Study, those interactions must be developed. SAFGRAD is the central coordinating group for the Africa Case Study, and now units and individuals in Africa need to be identified for outreach activities.

Copies of the Beijing (China) Workshop Report, the PAN-EARTH Annual Report, and the Report of the Global Climate Change Conference recently co-sponsored by Cornell University in New York City have been sent to all who are attending this workshop.

All the participants then introduced themselves and explained their areas of expertise.
Figure 3

**WHAT PAN-EARTH SCIENTISTS CONTRIBUTE**

- GCM outputs specific to region
- ecological and agricultural models
- other methodologies
- existing international, multi-disciplinary network
- expert judgment on global systems

**WHAT NATIONAL SCIENTISTS CONTRIBUTE**

- understanding of specific agricultural systems
- understanding of specific ecological systems
- climatic data for region
- crop productivity/soils data for region
- expert judgment on regional systems
OFFICIAL WORKSHOP OPENING

Cheikh Abdoul Khadre Cissoko, Minister of Rural Development for Senegal, officially opened the PAN-EARTH Sub-Saharan Africa Workshop. A summary of his remarks is presented below; the complete text, in French, follows.

The Minister welcomed all the African and international participants in the name of President Abdou Diouf, his government, and the people of Senegal. The theme of this workshop is one of the most important scientific issues, to study the causes and effects of changing climate on the agricultural and ecological systems of sub-Saharan Africa.

The Minister expressed his support for the desertification action plan adopted at a conference in Nairobi by a number of African countries, including Senegal. That conference adopted the concept that countries that are affected by adverse environmental effects should help one another. The conference also adopted 28 resolutions to address climatic imbalances in the region. Interactions among African countries and internationally should constitute the major impact of such conferences and seminars.

The African traditions and the major effects of drought are a set of challenges for the fragile environment and economies. Setting up national and international infrastructures for North-South and South-North cooperation are important. Setting up ecological and agricultural models for major crops, collection of data for a data base, and multidisciplinary efforts assessing effects in sub-Saharan Africa are all important goals. In Senegal, data are being obtained, and all associated centers working together have achieved a rich data base for grain crops and rain-fed crops. Enhancing computer capabilities is an important outcome of these international efforts. In spite of laudable drought research efforts and solutions offered by many different scientists, there is still a need for an interdisciplinary approach. After many years of successful trial and effort, governments must take stock of efforts, to channel them to better use and to enhance scientific cooperation.

The creation of the PAN-EARTH Sub-Saharan Africa Case Study, coordinated by SAFGRAD and Cornell University, is important to strengthening scientific cooperation. The research network to be created for this Case Study in sub-Saharan Africa will complement the existing networks and will enhance the ongoing network activities. The diversity and number of high caliber scientists involved is important. The next five days of this workshop will be used to test the physical/biological interface methodology and form a program of future activities for the PAN-EARTH Sub-Saharan Africa Case Study. Your agenda is difficult but I believe that your work will be fruitful and will result in a list of pertinent recommendations and proposals to create a vast case study to which the Senegalese government will be attentive.

The Minister then declared open the PAN-EARTH Workshop on Effects of Climate Change on Agricultural and Ecological Systems in Sub-Saharan Africa.
Monsieur le Représentant du Ministre de la Protection de la Nature
Monsieur le Représentant du Ministre Délégué auprès du Ministre du Développement Rural chargé des Ressources Animales
Monsieur le Gouverneur de la Région de Thiès
Monsieur le Préfet de Mbour
Messieurs les Représentant du PNUD, de la FAO, de l'USAID, du CRDI, de la Fondation FORD et de l'Université de Cornell
Monsieur le Directeur Général du SAFGRAD
Mesdames, Messieurs les Séminaristes
Honorables Invités.

Je voudrais tout d'abord, au nom du Chef de l'État, le Président Abdou DIOUT, de son Gouvernement et de l'ensemble du peuple sénégalais, souhaiter la bienvenue en terre sénégalaise à tous ceux qui ont accepté de venir, parfois même de très loin, participer à cet atelier international portant sur un thème d'actualité brûlant pour le monde en général et l'Afrique subsaharienne en particulier. Je puis vous assurer que c'est avec plaisir et non sans fierté que nous avons accueilli le choix porté sur notre pays pour abriter ce forum scientifique auquel prennent part plus d'une centaines de spécialistes qui, de la Météorologie/Climatologie, qui, de l'Ecologie, de l'Agriculture et représentant, entre autres quinze pays africains, les États Unis d'Amérique, le Japon, l'Australie et le continent Sud-américain.
Le thème de cet atelier est d’actualité disais-je parce que portant sur la compréhension scientifique des causes, des rétroactions et des effets des changements climatiques sur les systèmes agricoles et écologiques d’Afrique sub-saharienne.

En effet, de par le monde, le constat reste unanime sur le fait que les écosystèmes et les systèmes agricoles de la plupart des pays au sud du sahara ne cessent d’être mis à rude épreuve par les changements climatiques dont la manifestation la plus éclatante et inquiétante est assurément la sécheresse accablante, sévissant depuis bientôt une vingtaine d’années. Les effets de ces changements climatiques et de la sécheresse induite sur l'environnement sont multiples et je n’en citerai que les plus préoccupants pour nos économies nationales et nos ressources naturelles : désertification galopante, raréfaction des paturages naturels avec son cortège habituel de cheptel décimé; dégradation des systèmes agricoles dans le sens d’une baisse de la productivité et de la production au sein des exploitations agricoles en général et celles à base de cultures céréalières en particulier; érosion éoliennne et hydrique avec baisse de la fertilité potentielle des sols; forte salinisation des terres de plaines alluviales ou fluvio-marines rendues de ce fait impropres à la riziculture submergée ou irriguée.
Manifestation la plus spectaculaire des changements climatiques, le phénomène de sécheresse-désertification en Afrique sub-saharienne aura fait l'objet tant au niveau national, régional, sous-régional qu'international de la mise sur pied d'instances et de la tenue de plusieurs séminaires et conférences sous l'égide des Nations Unies et assortis d'un train de Plans d'Action de lutte sur la base de résolutions. C'est ainsi que mention peut être faite de :

(1) - la création en 1972 du Comité inter-État de lutte contre la sécheresse dans le sahel (CILSS) qui, pour les besoins de la cause a implanté à Niamey le Centre AGRHYMET impliqué dans les investigations agroclimatiques dans la sous-région avec l'appui de l'Organisation Mondiale de la Météorologie.

(2) - la conférence tenue en Septembre 1977 à Nairobi à l'issue de laquelle un Plan d'Action de lutte contre la désertification a été adopté lequel comportait 28 résolutions dont l'une des plus importantes a trait à la formulation des stratégies nationales et leur insertion dans une politique intégrée d'aménagement du territoire ;

(3) - la 85 ème session plénière de l'Assemblée générale de l'Organisation des Nations Unies tenue le 15 Décembre 1988 et qui, dans sa résolution 3386 (Mesures
à prendre en faveur de la région soudano-sahélienne) décida d'assigner au Bureau des Nations Unies pour la région soudano-sahélienne, je cite :
"le rôle de mécanisme des Nations Unies chargé d'appuyer, pour le compte de son programme pour l'Environnement, les efforts en vue d'appliquer le Plan d'Action adopté à Nairobi";


Cette conférence aura, entre autres, retenu la notion de "pays agressés par la désertification" (P.A.D.) et formulé un train de résolutions allant dans le sens de la recherche de solutions pour le renforcement de la Coopération sud-sud dans le domaine de la lutte contre la sécheresse et la désertification.

La mise en exergue de la nécessité impérieuse d'une concertation et d'une coopération tant au niveau régional et sous-régional (entre pays africains) qu'international (entre pays africains d'une part, les bailleurs de fonds et les Institutions du système des Nations Unies d'autre part) constitue sans aucun doute le dénominateur commun de la plupart des résolutions prises lors de ces séminaires et conférences.
Mesdames et Messieurs, les changements climatiques en Afrique sub-saharienne avec leur cortège de sécheresse, désertification, dégradation des écosystèmes agro-pastoraux, baisse de la production agricole constituent assurément une série de défis interpellant nos États aux économies si fragiles. Le relèvement de ces défis requiert la mise en œuvre de stratégies nationales conjuguées avec des efforts de renforcement de la Coopération sud-sud et nord-sud. Au demeurant, ces stratégies nécessitent pour leur formulation une série de données scientifiques dont les principales demeurent :

. la connaissance et la compréhension des causes, rétro-actions et effets des changements climatiques sur les écosystèmes et les systèmes agricoles

. la mise au point de modèles écologiques et agricoles génériques pour les principales cultures

. la collecte, l'analyse de données agroclimatologiques à des fins de constitution d'une base de données.

C'est dire l'importance des efforts de recherches multidisciplinaires à déployer dans ce domaine en Afrique sub-saharienne.

Au Sénégal, les Institutions impliquées dans les études agro-climatiques et la mise à la disposition des décideurs de données scientifiques sont : l'Institut sénégalais de Recherches agricoles
de Suivi Ecologique et l'ORSTOM. C'est ainsi que l'ISRA poursuit depuis 1975, en étroite collaboration avec la Direction de la Météorologie Nationale un vaste programme de recherches multi-disciplinaires en Agrobioclimatologie ayant à ce jour à son actif une riche base de données agroclimatiques, des données sur les besoins en eau des principales cultures pluviales, un modèle de simulation du bilan hydrique pour les besoins de prévision de la production agricole. Le renforcement de l'équipement de ce programme de recherche en matériel informatique et la collaboration avec l'ORSTOM matérialisée par le développement de l'Unité de Traitement de l'Information Satellitaire (UTIS) de Dakar et l'installation au mois de Septembre 1988 d'une antenne de réception satellitaire Météostat à Dakar ont ouvert de nouvelles perspectives en matière de recours aux techniques de télédétection pour la production en routine de cartes de pluviométrie estimée à partir des images satellitaires complétées par les informations météorologiques de surface. Sur le plan sous-régional, l'ISRA est partie prenante du réseau Espace AGRHYMET regroupant les services nationaux de météorologie et les Institutions nationales de recherche agronomique des 9 pays membres du CILSS et ayant pour objectifs :

- la réalisation de synthèses des acquis en matière d'Agroclimatologie opérationnelle et son application au suivi de l'hivernage et à la prévision des rendements

- le développement de l'échange d'informations et des contacts entre chercheurs des différentes composantes nationales.
S'agissant du Centre de Suivi Ecologique, qui n'est autre que la suite logique du Projet de Surveillance continue des Ecosystèmes Pastoraux Sahéliens financé par l'UNESCO, ses acquis en matière d'élaboration et de diffusion de cartes d'évolution de la biomasse dans le temps et l'espace font notoriété tant sur le plan national que sous-régional.

Sur le plan institutionnel, le spectre de la sécheresse endémique a conduit les autorités sénégalaises à mettre sur pied un Comité Interministériel de Suivi de l'hivernage présidé par mon Département et ayant pour mandat de statuer, sur toute l'étendue du territoire, sur l'évolution de la pluviométrie, l'état des cultures, le parasitisme et les prévisions de récolte.

Mesdames, Messieurs, Chers séminaristes vous conviendrez avec moi, qu'en dépit d'un effort louable de recherche portant sur l'esquive de la sécheresse, les solutions actuellement esquissées par les agrométéorologiques, les physiologistes, les généticiens, les agronomes sont pour les moins partielles et nécessitent une approche pluridisciplinaire à même de permettre d'aboutir à des synthèses écologiques harmonieuses au niveau de chaque écosystème donné voire de chaque système agricole. Aujourd'hui, après de nombreuses années de tatonnement plus ou moins réussi, alors qu'on a déjà réuni des quantités très importantes d'informations de tous ordres, il convient de faire le point dans tous les secteurs, d'établir des priorités pour mieux canaliser les activités et donner des orientations claires. De ce point de vue, l'organisation en réseau thématique et le renforcement de la
coopération scientifique et technique ouvrent de nouvelles perspectives. La création du Réseau d'Evaluation Prévisionnelle pour les Réponses Ecologiques et Agricoles aux Activités Humaines (PAN-Earth) coordonné par l'Université de Cornell à un niveau global et par l'OUA/CSTR/SAFGRAD en Afrique sub-saharienne procède sans aucun doute de cet impératif d'organisation et de renforcement de la coopération scientifique.

J'ai noté à travers les objectifs assignés au réseau PAN-Earth à créer en Afrique sub-saharienne, que celui-ci ne peut qu'être complémentaire du réseau Espace AGRHYMET déjà opérationnel au niveau des 9 pays du CILSS. Ce deuxième atelier à l'actif du projet PAN-Earth devant, entre autres, jeter les bases de la mise en œuvre du dit réseau ne peut qu'être salué avec grand éclat. Son importance est reflétée par le nombre de sommets scientifiques et la diversité des expériences ici réunies.

Mesdames, Messieurs les séminaristes, durant cinq jours vous allez devoir vous consacrer à l'initiation des analyses d'études de cas en Afrique, au test de la méthodologie d'interface physique/biologique et surtout à la programmation des activités futures d'études de cas de Pan-Earth en Afrique. Votre calendrier est certes chargé mais je reste persuadé que vos travaux seront fructueux et déboucherez sur un train de recommandations pertinentes et des propositions de mise en œuvre d'un vaste programme d'étude de cas auxquelles les autorités sénégalaises ne pourront qu'être attentives.
Je ne saurais terminer cette allocution sans remercier le Programme des Nations Unies pour le Développement, le Centre de Recherches pour le Développement International, la Fondation Ford pour leur soutien financier à l'organisation de cet atelier.

En souhaitant plein succès à vos travaux, je déclare ouvert le deuxième atelier Pan-Earth sur les effets des changements climatiques sur les systèmes agricoles et écologiques en Afrique sub-saharienne.

Je vous remercie.
PRESENTATIONS

For the remainder of the first day's sessions, presentations were made on climate modeling, biological effects of climate change, and collaborative research networks in Africa. The rapporteurs for these sessions were Drs. M.V.K. Sivakumar, M. Traoré, and C. Harwell.

Dr. Richard Turco, University of California, Los Angeles, USA

The first presentation, on "Global Change and Nuclear Winter: Co-Development of Model Analysis," was made by Dr. Richard Turco of the University of California, Los Angeles. Dr. Turco explained that certain principles of global climatic change are common to nuclear winter and increased greenhouse gas production (Figure 4). He discussed the radiative/microphysical properties of aerosols and gases, and energy balance processes (hydrological cycle and boundary layer). In the energy balance of the ambient atmosphere, the normal greenhouse effect is produced while in the nuclear winter smoke-perturbed atmosphere, large clouds of smoke produce an anti-greenhouse effect (Figure 5). The resulting reduction in sunlight will produce significant cooling. In sub-Saharan Africa, nuclear winter is not expected to cause significant changes in temperature, but will induce changes in rainfall through depressing convective effects; models are not precise on the distribution of effects (Figure 6). Smoke is expected to cause reduced precipitation in the tropical monsoon regions.

Another major problem is depletion of the stratospheric ozone layer caused by nuclear war. General Circulation Models (GCMs) can now predict the ozone layer mass density for unperturbed and perturbed states (Figure 7). This information relates to other types of perturbations of the ozone layer, such as from chlorofluorocarbons (CFCs).

Studies of nuclear winter have led to significant improvements in models used to simulate processes that affect climate and climate change. Nuclear winter research has bridged fundamental interdisciplinary barriers between the geophysical and biological sciences. Ongoing nuclear winter research projects will continue to improve understanding of the Earth's environment and the ability to model changes from the natural state.

The discussion following centered around the implications of the conclusions from nuclear winter studies.

Dr. Tom Ackerman, Pennsylvania State University, USA

Dr. Tom Ackerman from Pennsylvania State University made a presentation on the theoretical background of the General Circulation Models (GCMs). He emphasized that GCMs are not specifically adjusted to tropical conditions. A coupled atmosphere-ocean-ice-Earth climatic system was schematically presented showing the external and internal processes in climatic change (Figure 8). GCM processes involve modeling the atmosphere and surface-atmosphere interactions; they have a mid-latitude bias, in order to compute surface temperatures. Several dynamic equations involving conservation of momentum, mass, energy, and mass for water
GLOBAL CHANGE AND NUCLEAR WINTER: CO-DEVELOPMENT OF MODEL ANALYSIS

RADIATIVE/MICROPHYSICAL PROPERTIES OF AEROSOLS AND GASES

ENERGY BALANCE PROCESSES:
  • HYDROLOGICAL CYCLE
  • BOUNDARY LAYER

REGIONAL TRANSPORT/DISPERSION MODELING

GLOBAL CLIMATE SIMULATIONS WITH CHEMICAL AND AEROSOL TRACERS

STRATOSPHERIC OZONE DEPLETION
FIGURE 5
ENERGY BALANCE IN THE AMBIENT AND PERTURBED ATMOSPHERE

Normal Greenhouse Effect

Visible

Infrared

Smoke Perturbed Atmosphere

Visible

Infrared

Layer of CO2 & H2O
FIGURE 7

OZONE MASS DENSITY (KG/M$^3$) X 10$^9$

UNPERTURBED

PERTURBED AFTER 20 DAYS

TRANSPORT ONLY (NO CHEMISTRY)
vapor, and physical equations for heating, cooling, surface fluxes, and cloud processes were used in constructing the GCM (Figure 9). Examples of topographic heights, sea-surface temperatures and land-sea-ice distribution used in the simulation model were shown.

GCMs could be used as climatic models by constructing a best-estimate model and running the model for extended periods and by averaging the variables over the last section to get a control climate. A perturbed model is run and the difference between the perturbed and control model is used to determine the climatic effect. Examples of simulated zonal wind, surface air temperature, and rainfall have been shown. In modeling the hydrological cycle, several complications arise because the processes are basically sub-gridscale and are highly temperature dependent (Figure 10).

GCMs can predict large-scale temperature and wind fields, seasonal cycles of temperature and circulation, and zonal-average energy budget. However, they do not do well in predicting the regional climate features, diurnal effects, clouds, precipitation, surface energy budget, and internal climate variability.

The discussion on Dr. Ackerman's paper was focused on the performance of GCMs. It was stressed that GCMs do fairly well for the temperate regions, but currently not for the tropics. The model cannot be modified to give preference to rainfall instead of temperature. It is unlikely that rainfall could be predicted. In response to a question as to whether tropical conditions could be better simulated if more ground truth data are available, Dr. Ackerman explained that there are no data over tropical oceans and lack of data is a difficult problem. A much higher resolution is needed for the tropical model. Regional-level models could only be created by shrinking the entire scale of the GCM, which greatly increases computation time, or by making fine resolution models over a limited area, then using the larger models for boundary conditions; this latter approach should be explored further for the tropics.

Dr. Alan Robock, University of Maryland, USA

In his presentation on "GCM Greenhouse Warming Scenarios for Africa," Dr. Alan Robock of the University of Maryland emphasized that the coarse resolution of the climate models limits the ability of the models to produce valid simulations on a global scale. Also, for specific applications to agriculture, the sensitivity of the model is not well understood. Predominant changes in all the activities in the past century have been technological changes, and their interactions with climate have not been considered.

In producing climate change scenarios, use of information from the instrumental record has a limitation in that, for different causes, it may produce an entirely different distribution of climate parameters. Use of paleoclimatic information also has the same problem.

GCMs could be used for climate scenarios, and a comparison of five different models (OSU, NCAR, GISS, GFDL, and UKMO) showed that they disagree on the regional distribution of climate change. Although they could be used to
FIGURE 9

Dynamical Equations

1. Conservation of Momentum
   ⇒ 2 predictive equations for horizontal wind
      (requires frictional dissipation terms)

2. Hydrostatic Equation
   ⇒ diagnostic equation relating height and pressure

3. Conservation of Mass (Continuity)
   ⇒ predictive equation for density

4. Conservation of energy
   ⇒ predictive equation for temperature
      (requires diabatic processes: radiation, condensation, etc.)

5. Equation of state
   ⇒ diagnostic equation relating p, T, and ρ

6. Conservation of Mass for water vapor
   ⇒ predictive equation for water vapor
Figure 10

HYDROLOGIC CYCLE

Modeling Complications:

- All processes are basically sub-gridscale
- Cloud microphysical processes not completely understood
- Large variety of timescales
  - microphysical processes on the timescale of seconds
  - ice sheet changes on the scale of decades
produce physically consistent scenarios, they still have large deficiencies in their ability to predict the future. It cannot be assumed that climate will gradually warm; it may be entirely due to internal variations in the climate system. Secondly, GCMs do not properly consider many important physical and biological processes. GCMs cannot even do a good job of reproducing the current climate. The variability of climate may also change as the mean changes.

In view of the above limitations, Dr. Robock suggests a multidisciplinary approach to produce useful scenarios on a short-term basis. This would employ the expert judgment of climatologists, utilizing the GCM output and their knowledge of the climate and microclimate of the regions of the studies to produce a set of arbitrary, reasonable, simple scenarios of the required parameters. It is important to proceed with methodology development now and better data can be added later.

Dr. Mark Harwell added that there are many uncertainties on all sides; scientists have to be aware of these but not overwhelmed by them. The objective is to take the climate models’ output and, through applying reasonable expert judgment, interpret that to obtain appropriate scenarios for looking at climate change effects. The Sub-Saharan Africa Case Study will use the expertise and judgment of scientists to come up with a range of scenarios. The biological models can examine a full range of precipitation and temperature changes and sensitivity analyses can be performed.

The full text of Dr. Robock’s presentation appears in Appendix A.

**Dr. Wendell Cropper**, University of Florida, USA

Dr. Wendell Cropper of the University of Florida presented an "Overview of Important Issues for Biological Effects from Climate Change." He stated that it was easy to become skeptical about global climate models; but one cannot wait until all uncertainties involved are resolved. Skeptics assume that it is better not to worry about uncertain things, that one should assume things will not change for the worse. He suggested a pluralistic approach: try all kinds of different methods to get an overall picture of possible problems and solutions; get an idea of ranges for climate change to use for sensitivity analyses; and look at the sensitivities of biological systems to see if climate changes for that system are important. When dealing with systems with thresholds, severe biological impacts may be felt even though the average temperature may be above the threshold.

Different methods can be used for analyzing for specific factors. *Historical analogs* give a concept of impacts from similar problems. This is especially useful for extreme events, such as the "year without a summer" in 1816, and the extreme heat and drought of 1988. *Paleoecological analogs* may be used for evaluating climate change effects on ecological systems. By examining how biomes shifted, shown in the pollen record, as climate changed over geological times, shown in ice-core and other records, it can be estimated how a future climatic change will cause biome shifts.
But projected greenhouse changes will be very rapid in comparison to ice retreats. Many ecologists are unable to determine if tree species can migrate quickly enough to accommodate climate shifts. Statistical models are used to relate biological effects to climatic parameters based on actual experiences. For example, the PAN-EARTH Japan Case Study is using a statistical model for rice production in Japan. One problem is the equations do not have any of the mechanistic responses to climate change. Physiological data can be used to integrate by asking, for interested species, what is the range of climatic factors that can be tolerated. For rice, this is a very useful approach, since that crop is so temperature-change intolerant at certain growth stages. This method is very useful for agricultural systems, since yield is the central question.

Simulation models are available for certain ecosystems and crops. The IBSNAT models are available here, as are grassland and pastoral ecosystem models. A minimum data set is necessary to make a usable simulation over broad geographical areas. Input necessary for the crop models relate to soils, crop cultivar types, and a series of climatic and cultural data. These models do well at predicting plant biomass and yield over the growing season when they are carefully calibrated to site-specific conditions. In some cases, the models do well with 30-day means for climate inputs. But there are some situations where averaging makes a big difference, and one must be careful to examine this.

Researchers must look beyond direct effects on plants to indirect effects on ecosystems, such as fire spread and frequency. There are different sensitivities at different stages in life cycles; questions need to be asked about effects on animals when the biome changes, effects on consumers, predator-prey shifts, effects on ranges of pests and changes in pest activity, and interactions with whole system structure and function. Sea-level rise has potential extreme coastal effects; there may be major impacts on migratory species and coral reef effects.

In the SCOPE-ENUWAR study of the consequences of nuclear war, it was emphasized that one of the primary impacts is through indirect societal effects, including devastation of the world economy and impacts on exports of food and medicines. Africa would feel these impacts as well as the precipitation changes; a long process of study of this concludes that much of the world is subject to starvation after a nuclear war.

Agricultural technology is not independent of climatic variations; there is not a simple biological response, but a series of complex social and economic responses. The IBSNAT/DSSAT crop models feature the ability to do strategy simulations: given a current uncertainty in climate, one can question about the proper varietal to plant, a statistical question that the DSSAT system is set up to answer. It can determine the statistical distribution of yield if given certain variables.

The proper approach is to use many avenues to understanding climate change effects; expert judgment is the key to understanding climate change in most localities. The models to be implemented here do have phenology built into
them, including differential sensitivities, and by doing a suite of sensitivity analyses, one can get at some of the issues of extreme climate events; but all models have issues they do not cover, so one must do the whole range of types of analyses.

Dr. Miguel Acevedo, University of the Andes, Venezuela

Dr. Miguel Acevedo, University of the Andes, Mérida, Venezuela, spoke on "Biological Effects of Global Climate Change in Venezuela," giving examples from Venezuela of effects identified as potentially important. In tropical areas, precipitation is more important than temperature changes; but confidence in GCM results is lower for precipitation and for tropical regions. A close examination of the effects on hydrologic systems is needed, and indirect effects on biological systems due to hydrologic changes; examples are changes in river beds due to changes of flow, and changes in estuarine systems. For tropical areas, forests and savannas are key systems to consider, individually as well as interactions and shifts between the two systems. The importance of seasonally-flooded savannas must be stressed, especially in Venezuela, where this constitutes a large part of the country. For aquatic systems, researchers must look at rivers, lakes, artificial lakes, coastal, and marine systems. To determine ecological effects and hydrological effects, one should also look at indirect effects on ecological systems, such as saltwater intrusion. There are important major river deltas located in tropical areas, such as the Orinoco, that are very sensitive to saltwater intrusion.

For agricultural effects, crops, grazing, and forest plantations must be examined. In examining agricultural effects for tropical countries, an important emphasis is demand for irrigation and shifts in production areas. Many developing countries are located in tropical areas, which are important to the world for future development.

Dr. Taye Bezuneh, SAFGRAD, Burkina Faso

Dr. Bezuneh addressed the workshop on the "PAN-EARTH Collaborative Research Network Approach to Characterizing Effects of Climate Change on Food Production in Sub-Saharan Africa." The PAN-EARTH Project studies will include sustainability issues for ecology and agriculture; the Africa Case Study will deal only with countries that can be represented within the network. Climate change has been proceeding faster in Africa than in other continents because it is primarily human-induced here. There are some agroclimatological data and long years of agronomic data in some countries in Africa, but 20-30 years of data have not been correlated to the current systems of production. One of the new network activities will be to relate the available data to current conditions; expert judgment will be involved. Each institution and country will have to test these models to use on the statistical data available.

Scenario studies are very valuable in the African situation. Climate changes have policy implications. The scenarios developed here will expand our views of how to manage the future changes. There are some good climatologists and
agronomists in these countries, and they direct the research in these countries. The blending of ecologists, agriculturalists, and climatologists will allow us to integrate methodologies and look at systems holistically. SAFGRAD currently has five networks; the link to IBSNAT has to be more aggressive, which will be to our benefit and to provide feedbacks.

The central objective of the PAN-EARTH Sub-Saharan Africa Case Study is to characterize the vulnerability of African nations to global environmental change and to ascertain its critical importance to sustainable development in the region. Other salient objectives are to:

- orient scientists and institutions in sub-Saharan Africa to the apparent global climate changes as they affect the sustainability of the different agricultural and ecological systems in Africa through case study analyses to be initiated in various countries of the region;
- improve scientific capabilities of scientists and institutions of the region in order to make analysis and characterization of the long-term climate data base available and relate such findings to the apparent causes of African agrarian crises and ecological deteriorations;
- facilitate the exchange of technical information among African countries on development and application of crop production models;
- study the effects of plausible climatic change scenarios on the productivity and sustainability of agricultural and ecological systems; and
- through extensive sensitivity analyses, identify the most important climatic change with agricultural and ecological effects in Africa, so that climate modelers can redirect research to reduce uncertainties about those critical factors.

Implementation of the Case Study will involve:

- specification of physical scenarios, including new approaches to link GCM output to statistical, biological, and climatic data;
- implementation of ecological and agricultural models calibrated to specific selected systems in Africa; and
- acquisition and characterization of agricultural, meteorological, and other related data for different ecological zones, through country-level case studies.

One objective of this workshop is to get each participant to identify problems to fit into the scenario-building activity. Some criteria are: ecological zones—savannas (Sahel, Sudan, Guinea); humid coastal zones (forest ecology); and Eastern African—highlands, dry land ecologies. Climatic stresses include: changes and shift of precipitation; drought and temperature trends; and both warmer and cooler hydrologic systems. Biological stresses and human activities include population growth issues.

Agricultural activities of concern include: shifting cultivation cannot continue; nomadic and pastoral systems; edaphic factors; and soil types. Data bases and availability of researchers vary from country to country; what matters is not the numbers but the level of interest.

The length of the Case Study will be defined by the identified problems, those which will be of interest to scientists; funding must be obtained within the next six months. Two to three years
after that should be adequate to complete the studies.

Dr. Harwell added that the PAN-EARTH Project does not have the long-term plans of the International Geosphere/Biosphere Program (IGBP); they are trying to improve the global database on these issues; PAN-EARTH is more focused on using existing data bases and knowledge to evaluate potential effects now; IGBP will continue long after this Project is completed. Dr. Bezuneh continued by adding that the whole idea of networking is excellent; it works well with limited resources, especially with shortages of materials (books and money). The shortage of manpower is extremely important; training within the groups is important to interpret the large amounts of data available. Dr. Harwell stated that he is aware training is an important component, and bringing the IBSNAT crop models to this workshop is a part of this process. He is working with the IBSNAT network to put together a training conference in Hawaii within a year for modelers from all over the world, from each of the case study countries; he welcomes ideas for a proposal for this and ideas on how to put on such a workshop.

The full text of Dr. Bezuneh’s presentation appears in Appendix A.

TUESDAY, 12 SEPTEMBER 1989

PRESENTATIONS

During the entire day, presentations were made by the African scientists. Chairman of the morning session was Dr. Taye Bezuneh; the rapporteur was Dr. J.J. Owonubi. Chairman of the afternoon session was Dr. Paul Nkwi; the rapporteurs were Drs. D.M. Osafo and C. Harwell.

Dr. Madiane Diagne, Senegal - The Effects of Climate Change on the Production of Millet

The presentation and paper discuss the problems of changing scale in the production of millet. In Senegal, there are relationships developed between millet production and climatic data from 25 stations well-distributed over the territory. When the research was first performed, the results were not good, there was not a good correlation of crop yield to rainfall; there are other variables not taken into effect. It is possible to validate a simulation model related to water balance; for a simple model, use the rainfall distribution between human use, runoff, drainage, sink, and evaporation. It is important to look at water that is efficiently used for agriculture, not just for yield alone but also for irrigation uses and other water uses. Agrometeorological data are currently at the station level, and the objective is to move to a new scale. Remote sensing can be used as a tool to give a finer resolution picture. Researchers have the parameters needed, but need the methodology to move from one scale to another.

The paper is presented in Appendix A, in French.
Dr. Moussa Traoré, Mali - The Effects of Climate Change on the Production of Sorghum and Millet in the Sudano-Sahelian Zone of West Africa

The presentation and accompanying paper highlight uncertainties in the production and productivity of sorghum and millet. The uncertainties relate to:
- shortened rainy season;
- reduced total rainfall;
- indefinite starting time of rainy season;
- varying intensity of rains; and
- uncertainties in predictions.

Specific problems raised in the paper concerned how to:
- match cropping to season;
- determine area of land cropped;
- identify areas affected by drought; and
- determine time of onset and retreat of rains.

Dr. Traoré explained that the "mean rainfall" values he gave are not actual rainfall, but rather averages weighted on the basis of 1984 production/area/rainfall. In further discussion, the participants agreed on the need for reliable statistics and observed that yields increased with rainfall only up to a point, beyond which rainfall is not the sole determinant of yield.

The paper is presented in Appendix A, in French.

Drs. L.N. Naju and J. Odak, Kenya (presented by J. Odak) - Climate Variabilities—Teleconnections in Kenya as an Early Warning System

There is farming in only one-third of Kenya; pressure on the land is extreme. Pastoral tribes keep goats and sheep; coffee, maize, and tea are the main crops.

The presentation estimated climate variabilities as part of a much larger project; the research done was to try to relate drought/flood to El Niño effects. They used records of rainfall and upper-layer temperature (300 mb) from 15 stations for comparisons. Particularly noted are indirect relationships of the temperature and rainfall regimes, such that cool temperatures ahead of the rainy season indicate the rainfall received for that year would be low. Upper air temperature observed in Kenya comes before observations of the sea surface temperature effects.
in South America, which had been mentioned in the literature as an indicator.

Comments after the presentation added that El Niño is a measure of sea-surface temperature, but there must be an atmospheric occurrence prior to that causing the El Niño event. It is difficult to say what happens, where, or when, but it is not impossible to correlate observations of temperature/rainfall changes at the surface from atmospheric changes, prior to observing sea-surface temperature changes.

Dr. E.G. Bonkoungou, Burkina Faso - *Effects of Climate Changes on the Sahelian Ecology*

The presenter gave statistics on the spatial and temporal variability of rainfall in the Sahel, especially noting:

- stations 5 km apart may have large rainfall variability;
- interannual variability is very marked in most world areas, but not in this area;
- a trend is for rainfall deficit/excess years to be followed by one another in decadal increments; and
- very high rainfall amounts can occur within short time intervals.

The presentation highlighted agents of degradation of the ecosystem, including human clearing for agriculture and dune formation. Unlike other dry areas, African savannas have been inhabited for almost 2 million years; these are the oldest human settlements in the world. Researchers must examine ecosystems in the light of this human influence. Mixed grassland and forest areas are common here, and this is difficult to model. In proposing a realistic approach to the regeneration of the Sahara, he suggested the Sahelian ecology be examined with respect to its moisture, fertility, fires, pastures grazing/wildlife, and human activities.

In discussions after the presentation, the participants agreed that the potential regeneration capacity of the Sahel and indeed other ecosystems in the region has not been assessed. It was noted that the integration of farming with tree growing required a program to contain the destruction of planted trees ahead of their maturity.

The paper is presented in Appendix A, in French.

Dr. Nestor Aho, Benin - *Effects of Climate Change on the Coastal Ecosystems of Benin and Togo*

The presentation began with works on carbon dating of pollen in lake cores from Lake Victoria, which traced the timing of previous droughts and different plant type concentrations in a historical perspective. Explanation of current trends showed that:

- rains in Togo are lowest in the western part of the country;
- the second rainy season is hardly useable for growing crops;
- annual variability in precipitation also has decadal cycles in this region;
- the last 20 years have been progressively drier; and
- droughts affected the source of water in mangrove areas, thus leading to higher salinity, and destruction of the mangroves (destruction of
mangroves also arises from the wood being used for cooking).

Cassava and maize are the main crops in the northern areas. Cassava can be grown in difficult conditions, but maize is more sensitive to climatic conditions, despite all other inputs. Historical savanna changes are to:

- destroy initial forest cover;
- cause death of hydrophyte species;
- select new varieties that are resistant to dryness; and
- adjust the species selection for rainfall, though local populations of humans are resistant to change to new non-local varieties.

Cultivated areas vary as the rainfall varies, and ways must be found to adjust to these variations; populations try to avoid the pains of the drought and maximize their per-hectare yield, but variations in area to be cultivated disallow this adjustment. Some useful perspectives are to:

- reconstruct the climate history of the area;
- elaborate models that will explain climate effects; and
- most important is to have models that will give appropriate seeding dates.

The paper is presented in Appendix A, in French.

Dr. M.V.K. Sivakumar, Niger - Climatic Changes and Crop Production Patterns in the Sudano-Sahelian Zone

The presentation began with an introduction to farming practices in the Sudano-Sahelian zone, particularly in Niger. Highlighted were:

- 3/4 of the country has inadequate rainfall and soils are poor in nutrients;
- <15% use animal labor, <5% of areas are plowed before planting, and <5% use recommended cultivars;
- millet production trends show increases only in regards to area planted;
- shift of isohyet is southwards by 150km since 1969; and
- there is obvious vulnerability in the event of further stress such as from climate changes.

August rainfall patterns generally reflect the annual pattern for averages; this is very important for making predictions, as August is the month for grain filling and flowering for millet, and thus rainfall is critical then. By analyzing the number of rainy days, amount of rain, and interval between rains, the presenter noted:

- less frequent rains since 1965;
- large standard deviations at the beginning and end of rainy season (more variability);
- significant dust hindering seedling emergence; and
- length of growing season itself reduced by 5-20 days across all locations in Niger.

The implications include:

- observable shifts in areas planted;
- reduced cash crops in favor of food crops;
- persistence of low rainfall leads to accelerated environmental degradation;
- cultivation of land subjected to a high degree of rainfall variability makes it susceptible to wind erosion, leading to progressive deterioration of land quality;
- increased pest outbreaks occur; and
- cropping has become more risky.
Participants noted the considerable hazards to farming in the Sahel and especially the limited options or flexibility. A proposal for the involvement of more animal power in farming was made to take advantage rapidly of the scanty rainfall.

Dr. Paul Nchoji Nkwi, Cameroon - *Climatic Change and Human Behavior*

Dr. Nkwi presented a paper concerning the human behavior effects of drought in sub-Saharan Africa. He stated that biodiversity includes the human species, all of which species ought to be preserved. The presentation included information on historical droughts in Africa.

The consequences of population movement caused by drought include: modification of settlement patterns; irregular food supplies; and the need to adapt to a new ecological niche.

Present trends include: an average annual population rate increase of 3-4%, and population doubling in 20 years. The population is 400 million now; this will triple by 2025.

The rural exodus has lead to:

- overcrowded cities;
- poor sanitary conditions;
- insufficient food;
- unemployment; and
- competition for resources.

Some current population policies are pro-natalist, and population growth in part results from ineffective birth control. A few countries can barely feed their population. A struggle for individual survival would result. Societal personalities will undergo a total review. Strategies include to:

- sensitize people to the dangers of some agricultural practices, such as deforestation, fires in the bush;
- associate the people in the elaboration of policies that seek to improve the environment and maintenance of biodiversity;
- associate people in the management of scarce resources; and
- systematically introduce environmental education into school curricula.

Survival depends on cooperation on all these issues by many of the people, not just by a few scientists.

A participant noted that a major change is transmigration, cross-borders, and he questioned whether this will occur during future droughts. Dr. Nkwi replied that he thought all borders around Africa should be open, a Pan-Africa should be encouraged; they live in the same ecological zones, and the boundaries are artificial. Historical splits because of colonialization will not last in times of stress.

The paper is presented in Appendix A.

Dr. J.J. Owonubi, Nigeria - *Overview of Climatic Change and Patterns of Crop Production in the Northern Guinea and Sudan Savanna Zones*

Dr. Owonubi presented a paper concerning crop production problems, particularly in Nigeria. Some problems with the data bases in Nigeria include:

- inadequate coverage;
- few stations with comprehensive data;
- lack of continuity;
- poor maintenance/supervision;
• lack of coordination; and
• almost nonexistent analysis.

The rainfall period length has shortened by thirty or so days since the 1960's; a reduction of rain is not as important as changes in the time of onset of the rainy season. Excess water has been used at times for irrigation. The timing of planting can change yields by as much as one-half; yields are also affected significantly by farming practices including irrigation. The Sahel region has moved southward from only about one-tenth of the country to about one-third of the area; this has caused crop types planted to change. Cereal crops are now more risky, and farmers are not planting them. Researchers have looked at the time of onset of the rains as opposed to the onset of seasons; there is a threshold that must be reached first.

For research on the harmattan effects, for temperature variations during the harmattan, there is only crude instrumentation, and thus researchers have only taken casual look at this. Some data show a drop to 60°C overnight, but there is no correlation between the data recorded and other observations. It is not certain that dust is controlling this temperature difference.

Responding to a question about using improved seed strains, Dr. Owonubi replied that it is easy to explain lower yields even though improved seed strains are used; the human factor comes into play after distributing seeds: the farmer reduces the fertilizer recommended to save money, or it does not get distributed on time. It is almost always a management issue.

The paper is presented in Appendix A.

Dr. E.O. Oladipo was to present a paper on "Climatic Analysis of Drought Situations in Africa" but was unable to attend. Appendix A contains the full text of a summary article prepared by Dr. Oladipo, containing much of the same material, entitled "Drought in Africa: A Synthesis of Current Scientific Knowledge," *Savanna*, 9:2, Dec. 1988, 64-82.

Drs. Kodjo Koulekey and Messan Gnininvi, Togo - An Example of the Effects of Human Activities on the Togolese Environment - Coastal Erosion

An increase in world temperature is linked as a cause of erosion. Studies of temperature trends find a positive slope for maximum temperature and for minimum temperature, and a negative trend for the medium for Lomé; there are problems with changing the scale. Precipitation in Lomé (in the south) in the 1980's included much flooding, but this was not a trend; annual rainfall in the 1980's was in the medium scale. There are erosion problems along the entire West African coast. The sector studied here is from the mouth of the Volta River (in Ghana) to Nigeria; sites were limited to an area between Lomé and Cotonou. The causes of the coastal erosion are multiple, but the study concentrated on the results of construction of ports and harbors.

Lomé built a port in 1964; the effects were to the west, accretion; to the east, erosion, a very normal reaction. From 1964-69, coastal growth 2m from the jetty was 60m/yr; in 1969-73, growth decreased to 28m/yr; in 1973-75, there was 18m of gain.
A questioner asked if human-influenced change outweighed in importance possible sea-level rise from global climate change. Dr. Koulekey replied that the prospect for significant sea-level rise is causing great concern in Togo because of the potential magnitude of coastal erosion, based on past, more limited experiences.

The paper is presented in Appendix A, in French.

WEDNESDAY, 13 SEPTEMBER 1989

The Wednesday morning session involved presentations of progress on the Venezuela, Japan, and China PAN-EARTH Case Studies; the afternoon session included presentations on the IBSNAT/DSSAT agricultural models, ecological models, and modeling demonstrations and training. The chairman was Dr. M. Harwell, the rapporteur was Dr. C. Harwell.

Dr. Miguel Acevedo - Report on the Venezuela Case Study

Dr. Acevedo reported on the results of the mini-workshops held in Venezuela in May, 1989, and the status of various endorsements and proposals. Each proposal is formulated for a particular funding agency interest. There are also pending international proposals to: the European Community (the tropical agriculture part of the development program); the World Meteorological Organization (WMO) through the local Venezuelan representative; and the International Foundation for Science's tropical agriculture program. There are plans to submit a proposal to the Interamerican Bank for Development and the World Bank. Dr. Acevedo detailed the connections within Venezuela research institutions, including the Ministry of Environment (several branches;) the Latin American Forestry Research Institute; the Interamerican Center for Land, Water and Development; the Air Force's National Meteorological Service; and the National Institute for Agricultural Research. He has been working with IBSNAT and with Dr. Rafael Herrera of the International Geosphere/Biosphere Program (IGBP). There has been work to establish a BITNET node in Venezuela for the PAN-EARTH Case Study and other international work. There is a complex network of institutions, and it takes a lot of coordination. The University of the Andes' School of Systems Engineering, Center for Modeling Simulation, and Laboratory of Tropical Ecology will be centers for advanced studies in tropical meteorology; the Physics Department will work on modeling atmospheric processes. The University of the Plains has done extensive work on maize in the plains and foothills; the University of Oriente has placed emphasis on coastal systems. The Case Study is working on the calibration of IBSNAT models with FONAIAP.

The mini-workshops in Caracas and Mérida in May identified important problems in Venezuela from climate change, and research options. Societal effects were discussed in both meetings, especially in Mérida, where many social/economics/political scientists attended. One important result is that the mini-workshop report is being used by the Ministry of the
Environment as a formal document concerning impacts of climate change in Venezuela (the report has been translated to English and will be available in early 1990). There is a need for further training of scientists, as a multi-disciplinary effort. Research needs to be done on changes in hydrologic cycles, impacts on city and rural planning population shifts, coastal demographic changes, and changes in social behavior such as industrial consumption. Venezuela needs some contingency plans to deal with these problems, especially the capacity of a democratic system to deal with global climate change effects. There is also a need for more scientists to be involved with human health problems from climate change and increased UV-B.

There will need to be further mini-workshops, which is a very cost-effective way to deal with these issues; there will be a November meeting for training with the IBSNAT models in Maracay; an ecosystem modeling mini-workshop will be held early in 1990; and a major workshop in February 1990 is possible. The emphasis will be on evaluating efforts already made.

In response to a question about whether this is a national project, Dr. Acevedo replied that this is an individual initiative but endorsed by three government agencies; these institutions are not explicitly expecting results, but will use the results for their policies and planning; the Venezuelan National Academy of Sciences strongly endorses the study, but they are not expecting the study to be done just so they can use the results.

Dr. Tatsuo Urabe, Nagoya University, Japan - Report on the Japan Case Study

Dr. Urabe began his report by speaking a little about the geography and population of Japan. The research groups there are concentrating on rice production; they have meteorological records for 120 years and also statistics on rice production. In the past 100 years, new cultivars have allowed rice production much further north than previously, which is good for analysis of nuclear winter effects. The Japanese scientists are waiting for CO₂ doubling data to do the analysis for rice of these changes.

In 1987, Dr. Mark Harwell organized a Japanese team, and sent a proposal to the government; three Japanese scientists went to the Beijing (China) workshop in August 1988: Drs. Uchijima, Kondo, and Urabe. The Japan Case Study has gotten domestic funding, but not international funding; science research funding comes from the Ministry of Education. The group is composed of individuals, but each has his own organization, and it is easy to link these organizations.

The Japan Meteorological Agency made a summary assessment of global climate change; based on that, an Agriculture Ministry committee reviewed global climate change effects. This group was chaired by Dr. Uchijima, so the national committee now is chaired by one of the Case Study members. The report concludes that increased temperature has a good effect on rice production, since Japan is on the northern limit of rice production, but each varietal has its own temperature limits, and Japanese farmers would have to change all cultivars. For fisheries, in the
northern ocean, salmon and cod would leave near-shore fisheries; for animals, pigs and cows would grow too fat if it were too hot. So Japanese scientists are now looking not only at rice but other problems. Drs. Harwell and Ackerman will come to Japan in October to review the work and make suggestions.

Dr. Mark Harwell - Report on the China Case Study

The China Case Study is well along; the problems there are different than in Africa: there they have central agencies and central funding. Professor Ma Shijun is the major sponsor of the China Case Study.

There are good data bases at all the ecological and agricultural sites selected for study. They are near meteorological stations with good data; they included forests; arid and semi-arid systems; tropical and sub-tropical systems; spring wheat and winter wheat; and rice. A computer on which the IBSNAT models were implemented was loaned to the China Case Study scientists. Data on soil types, cultivars, yields, and meteorological data were used to calibrate the models. There have been problems with communications; a computer disk with Chinese data has recently been received at Cornell. The ecological studies are looking at life zone classifications and biome shifts using an ordination technique which is not appropriate for nuclear winter temperature shifts.

Before 4 June 1989, the Case Study was very active; there are now a complete set of climate data for the Chinese research sites; also a University of California-Davis scientist has 30 yr/600 stations weather data for China.

The ordination method to be used in this case study involves collecting a series of data sets of species composed of ecological communities and then inputing the matrix to a computer model. There are a variety of techniques to distinguish different groups within community composition; this helps ecologists identify discrete communities, similar to principal components analysis. The ordination process changes axes to separate biomes more clearly; among these are climatic variables. The ordination for the whole country is done, and then climate change data are applied to see how biomes will shift; use of this process in Africa should be explored.

Dr. Michael Coughenour, Colorado State University, USA - Grassland and Pastoral Models

Dr. Coughenour presented a grasslands model (GRASS). It is a physiological-morphological model of grasses in the Serengeti/Tanzania that simulates: biomass; nitrogen; water (soil and plant); and heat. The time steps are: 1-2 days (growth); 2 hr (photosynthesis, solar radiation); 12 min (water, heat). The inputs are for: precipitation; temperature (reference, minimum, maximum); relative humidity; wind; and cloud cover (hours of sunshine/day). Latitude yields daily solar radiation input. There are parameters for: photosynthesis; growth; plant density; and soil properties.

A submodel deals with: number of shoots (different functional types); carbon distribution (blades/sheath, stems, flowers); photosynthesis
(carbohydrate pool, roots/crown); nitrogen (root uptake and distribution); and respiration.

The model was derived for a monospecies grassland, and it is best when used for one species or one functional group, but it can be used for multiple species; interspecific competition was not included.

The Century model will be coupled to the GRASS model in the future; Century models soil organic matter and nutrients. It simulates the transfer of plant residue into soil (two types of soil nitrogen), transferred among four nitrogen compartments in the soil, depending on turnover rates. Using this, soil fertility can be predicted for years to centuries. This demonstrates the effects of soil fertility on primary production; the model has been used in the Great Plains.

Dr. Coughenour also presented a Pastoral-Livestock Model. Northwest Kenya was the location of the original work and the model was validated there.

The model was used for the Turkana ecosystem, to analyze the flow of energy from plants, through livestock, to livestock products that become foods consumed by humans. The spatial distribution of primary production is determined as distributed in the system: calculate animal distribution based on the value of the habitat, then calculate various properties of the landscape that influence distribution of livestock. The model uses a normalized digitation vegetation index for a region from a geographic information system (GIS) soils map for the region; models use both soils and topography information. Rainfall maps provided very poor and sparse data; kriging was used to determine rainfall amounts across the area.

The simulation output from the pastoral model shows the distribution of livestock; the relationship between the distribution of livestock and vegetation can be seen. Using precipitation as the variable input (temperature is rather constant in the study area, and the seasonal variability is small and less important than other processes), this determines the size of range available. The availability and quality and quantity of forage for herbaceous and shrub intake determine the animal condition. This affects the birth rate and milk production and also influences susceptibility to disease and starvation. Also important are the transfer of livestock by raiding by bandits/other pastoralists (this is a common practice there).

**Dr. Gerrit Hoogenboom**, University of Florida, USA - Crop Models--IBSNAT

Dr. Hoogenboom discussed the background of the IBSNAT Project (International Benchmark Sites Network for Agrotechnology Transfer). IBSNAT has developed crop simulation models of two types: research and management. IBSNAT disks are available with user guides (free to developing countries). DSSAT is the Decision Support System for Agrotechnology Transfer, a complement to the IBSNAT crop simulation models.

All models are similar in structure: all are process-oriented computer models that simulate the whole process of the plant. Predictions start at planting and go all the way through
harvesting. The IBSNAT Project defined a standard set of input files needed for the models (Figure 11). They can run input files for all models; also the minimum data set has improved. Output sets are generalized for all models (Figure 12), and graphics are set to display output (Figure 13).

Input needs include: weather variables; soil variables; crop management inputs; genetic traits; crop parameters; reproductive development; carbon balance; water balance; and nitrogen balance. Some user selectable options for crop management inputs include: cultivar; plant density; planting date; irrigation; soil; and weather (location, year); (see sample soybean model [SOYGRO] output, Figures 14, 15).

The models have two weather generators, which can use daily or monthly input, and can then generate 50-100 years of weather data. Weather data input is most important. Much of these data are missing, especially in Asia and South America. There is a problem in generating precipitation data for tropical countries; another method is being developed for predicting rainfall for these areas.

The models look at development phases; each plant has different sensitivities to photoperiod and thermal regimes. The models use photo, thermal, and time accumulators to predict development phases (Figure 16).

The goal was to try to develop a minimum data set for systems analysis and decision making, trying to avoid the complaint that models will only work for the sites from which they were developed. The models do not currently handle intercropping, but it is realized that this is an important problem which needs to be incorporated into these models at some future time.

Text from an IBSNAT brochure and selected references are included in Appendix A.

The remainder of the afternoon session included model demonstrations and training sessions for the workshop participants.
FIGURE 11

INPUT

IBSNAT Standard
Minimum Data Set

FORTRAN Source
35 Subroutines

MODEL

Micro Computer
Daily Time Steps
< 1 min CPU

OUTPUT

IBSNAT Standard
Graphics
FIGURE 12

OUTPUT

- Total Canopy
- Leaf
- Stem
- Pod
- Seed
- Root
- LAI

BIOMASS

DEVELOPMENT

For Each SOIL LAYER

- Vegetative Stages
- Reproduct. Stages
  - # of Pods
  - # of Seeds
  - Shelling %
  - % Mature Pods
  - SLA

- Soil Water Content
- Root Length Dens.
- Soil Water Flow
- Soil Water Uptake
- Drainage
GAINESVILLE, 1978
BRAGG, IRRIGATED & NON-IRRIGATED

DRY WEIGHT, kg/ha

SOYBEAN

DAY OF YEAR

SEED IRRIGATED

CANOPY IRRIGATED

LEAF IRRIGATED

SEED RAINFED

CANOPY RAINFED

LEAF RAINFED

FIGURE 13
FIGURE 14

EFFECTS OF RADIATION ON SOYBEAN YIELD (SIM)

YIELD, Mg/ha

SOLAR RADIATION, E/m2-d

5  4  3  2  1  0

0  10  20  30  40  50  60
EFFECTS OF TEMPERATURE ON SOYBEAN YIELD (SIM)

YIELD, Mg/ha

TEMPERATURE, C

FIGURE 15
Development Phases:
- Pre-planting
- Planting
- Emergence
- Uni-foliolate
- Juvenile Phase
- Flower Initiation
- Anthesis
- First Pod Set
- First Seed
- Last Pod Set
- End Leaf Growth
- Physiological Maturity
- Harvest Maturity

Photo, Thermal & Time Accumulators
THURSDAY, 14 SEPTEMBER 1989

The entire day was devoted to the deliberations of the three working groups on: climatology, ecological effects, and agricultural effects. Reports from these three working groups are presented in the following section.

FRIDAY, 15 SEPTEMBER 1989

Chairman: Dr. Messan Gnininvi

REPORTS OF THE WORKING GROUPS

Climatological--Dr. Tom Ackerman
Ecological--Dr. Miguel Acevedo
Agricultural--Dr. Gerrit Hoogenboom

The three working group reports were presented in a plenary session, and questions and comments followed. Answers to significant questions have been incorporated into the texts of the final working group reports, presented below. The working group reports were adopted as read, with corrections.

CLIMATOLOGICAL WORKING GROUP

Co-Chairmen: R. Turco, J. Owonubi
Rapporteur: T. Ackerman

INTRODUCTION

Tasks for the Climatological Working Group:

• GCM/climatology comparison:
  control climates
  temperature, precipitation, seasonality
• African meteorological data base:
  what, where, when?
  how can we obtain it?
• Scenarios for Africa:
  simulations: Robock, CO2 X 2;
  Turco, nuclear winter
• Methodology:
  change in temperature (also soil temperature?)
  change in precipitation, drought frequency
  change in insolation, UV-B
  areas of influence
  station data
  GCM grid average-weighted
• Scenarios:
  for specific locations: CO2, nuclear
  winter; biology input
  scaling of large to small scales of GCM
  data
  data needs for biological models
• Proposals:
  to support the African research effort
• Plans for analyses, scheduling activities,
  assigning responsibilities

ASSESSMENT OF GCM CLIMATOLOGY IN AFRICAN CONTEXT

Temperature overall: The OSU model is considerably too warm; others seem more reasonable.

Precipitation Overall: The models do not show the dominant zonal pattern well enough; also, due to poor resolution, the models do not develop a strong enough gradient at the edge of the rain band. The rainfall amounts are variable,
sometimes too high, sometimes too low by factors of 2 or more. Regional variations in the model are too great, reflecting a lack of zonal continuity from one grid point to the next.

The GISS model pattern looks too much like a collection of bulls-eyes, rather than the observed strongly zonal patterns, particularly during summer. The OSU model seemed to be better in winter but not in summer, where it also did not develop a zonal pattern.

Assessments by country for each of the three models (GISS, OSU, GFDL) appears in Table 1.

DOUBLED CO₂ SCENARIOS

Temperature

Mean temperature: All models show a general temperature increase. Model averages show increases of 3-4°C across northern and central Africa both in summer (JJA) and winter (DJF). The range of temperature changes is on the order of 2-6°C. Therefore, the group recommends consideration of temperature increases of 2°C, 4°C, and 6°C for simulations of climate change. The baseline should be +4°C, the next most likely is +2°C, and the least likely is +6°C.

Maximum/minimum temperature: Only GISS has a diurnal cycle. GISS results show that in every month the range goes down as the temperature increases. Hence, the minimum increases more than the maximum. We infer that this is a result of increased downward infrared radiation both from the gases and from increased cloudiness. Therefore, we recommend that at all locations, but only during the rainy season, the diurnal range should be decreased. For a mean change of 2°C, increment the maximum/minimum equally. For a mean change of 4°C, increase the maximum and the minimum temperatures equally by 4°C during the dry season; increase the maximum by 3°C and the minimum by 5°C during the wet season. For a mean change of 6°C, increase the maximum and the minimum by 6°C during the dry season; increase the maximum by 5°C, the minimum by 7°C during the wet season. Sensitivity studies should include simulations with no change in the diurnal cycle, and possibly a +4°C, +8°C change for the mean +6°C case.

Precipitation

Based on current observations, some general conclusions about precipitation patterns can be drawn:

- Rainy season end is relatively uniform across the region and from one year to the next.
- Rainy season start is variable; in wet years, rain starts earlier.
- In a wet season, the intensity of the individual events is increased relative to a dry year. However, the frequency of events remains relatively constant.

- Summarizing the above, we arrive at the following typical precipitation envelopes for wet and dry seasons, with "normal" falling somewhere in between:
Within these envelopes, there are individual random events. The timing of these events does not change from wet to dry years, but only the intensity of individual events.

- In regions where the precipitation pattern has a double maximum, the variability of the two peaks is relatively independent of each other. Thus, either or both of the peaks may vary from wet to dry years. For example, wet and dry seasons might look like a double-maximum composite of the above figure or might look something like the following:

```
  | P | E |
  | R | C | I |
  | T | E |
  | M |
  | A |
  | N |
  | E |
  | R |
  | C |
  | I |
  | P |
```

- Based on the above, we recommend the following precipitation change scenario to be carried out at each site with a single precipitation maximum:

  a) determine the length of the rainy season;

  b) increase (or decrease) the length of the rainy season by a prescribed factor, fp, [values defined below] by moving up (or back) the start of the rainy season, while leaving the end of the season fixed;

  c) extend (or contract) the time series of rainfall by duplicating a fraction fp of the record in the middle of the rainy season and inserting it into the record at that point, thus leaving the start and the end of the season unchanged; [this assumption will be re-examined by climatologists from the various represented countries to see if this is an appropriate way of modifying the frequency component];

  d) in addition, increase (or decrease) the intensity of each rainfall event in the revised record by that same factor, fp;

  e) apply this technique for values of fp of: 1.32, 1.22, 1.12, 1.00, 0.87. (These factors should give changes in the total precipitation corresponding to approximately 1.75, 1.50, 1.25, 1.00, and 0.75, since the method increments both the onset of the rainy season and the intensity of each individual event.)

The baseline or most probable case is assumed to be the 1.22 (or about 1.5 total change) case. The next most probable case is the 1.25.

Two notes with regard to this prescription:

1) The latter two values of fp, particularly the last that implies a decrease in precipitation, reflect that observations show precipitation amounts in this region of Africa have declined over the last 20 years. Thus, it is possible that local factors may act to override the expected changes due to increased trace gas concentrations.

2) The total precipitation integrated over the season will change by a different factor at each site for any given year (rather than changing by a constant factor for all sites and all years). The ecosystem modelers should be aware of this and calculate the total precipitation change factors.

- For each site with a double precipitation maximum, we recommend that the above prescription be applied to each rainy season independently. Rather than do all combinations, it is probably sufficient to take the baseline case
(fp = 1.22) and apply it to the first peak, the second peak, and then both.

Solar Insolation

Model changes are less than ± 5% in total daily insolation. Hence, no changes in insolation for ecosystem simulations are recommended.

Wind

Wind changes in the large scale models are small and highly variable; hence, we have no recommended changes for overall wind speeds or directions. Other work suggests that increased CO₂ may lead to an increase in occurrence of large storms. Thus, we recommend that some consideration be given to the possibility of damage to ecosystems caused by more frequent severe storms.

Sea-level Rise

Sea level has been predicted to rise by about 1.0m through the next century. We recommend consideration of the impact of a sea-level rise of 0.5m and 1.0m on coastal regions.

**FOR THE RAINY SEASON; DURING THE DRY SEASON, DECREASE THE TEMPERATURE IN THE 150 Tg CASE BY 2°C AND BY 4°C.**

Sensitivity tests on each of the parameters include changes of -25% and -75%. As a further sensitivity test, these changes might be introduced at various times in the growing season (e. g., start, middle, near harvest) in successive runs to see what the effects of timing of the smoke effects might be.

UV-B fluxes could increase by some 10's of percents, but our information is limited. Any crops that are known to be particularly sensitive to UV-B damage should be considered in that context. The increase in UV-B due to various decreases in the ozone column are currently being computed and should be available for Ackerman in the next few months.

Ecological Systems

Due to the difficulty of convolving the initiation of smoke effects with the timing of the rainy season and the generally small temperature response, we have no recommended scenarios.

African Data Base

Generally, data are available over much of the area in question at various research centers and also from individual scientists. For example, among the countries represented in the group:

West Africa—Sivakumar reported that a west African data base on rainfall and temperature is available at ICRISAT in Niamey, Niger.

Nigeria—Owunubi presented data from 19 stations with records varying from 19 to 70
years. Available data consist of rainfall, temperature, and winds. Data are available on disk.

Senegal—Diagne reported that he has data at 25 stations in Senegal with records going back at least 35 years.

Kenya—Odak reported that records are available in Kenya going back in some cases 100 years. Older records are only temperature and rainfall.

Robock will begin the process of collecting data from various groups to develop a database. The plan is that some initial analyses will be carried out and then a proposal submitted to get funding for a detailed analysis and comparison to GCM output.

Some records of solar insolation are available. Generally, these are in the form of sunshine duration and perhaps total flux. Data will probably have to be calibrated to some extent in order to be used for model calculations.

**PROPOSALS**

General discussion concluded that cooperative research is possible. In particular:

* One likely area of funding from US sources (NSF?) is the further development of a rainfall climatology for the African region and the comparison to model outputs from the GCM. Since several scientists have been actively involved in constructing rainfall climatologies for Africa, we need to contact these people and determine which records are included in their databases and whether we can add substantial new information to them via the agricultural data.

* An associated project would involve analysis of the rainfall data for spatial and temporal patterns associated with large-scale circulation features and for the development of more refined impact scenarios.

**ACTION ITEMS**

* Meteorological data (rainfall, temperature, etc.) to Robock from Diagne, Odak, and Owonubi.

  * Initial analysis of data to be carried out by Robock.

  * Availability of meteorological journals from the United States to be investigated by Ackerman and Robock and sent to J.J. Owonubi.

  * African scientists to examine frequency of rainfall occurrence to see if CO2 scenarios documented here are appropriate; send results to Robock.

  * List proposed research, budgets, and resources needed for collaborative research and send to Robock.
TABLE 1
CLIMATOLOGICAL ASSESSMENTS OF MODELS BY COUNTRY

Nigeria

a) January Precipitation
   - GISS is an overestimate; most of the country receives no rainfall during January, except for the coast
   - OSU pattern is okay, but it should be drier
   - GFDL is the wrong pattern

b) April Precipitation
   - GISS has too much rain; there should be no rain in northern Nigeria or Niger
   - OSU pattern is good, but has three times too much rain
   - GFDL pattern is good, but is too high in the north

c) July Precipitation
   - GISS pattern is too far north and has too much rain
   - OSU pattern is wrong; it is too dry, and the rainband is not zonal-enough
   - GFDL amount and pattern are fairly good; there is uniform rainfall across the country

d) October Precipitation
   - GISS is too wet; in reality, very little rain was observed
   - OSU pattern should be more zonal, with rainfall farther to the south
   - GFDL pattern is wrong; there is too much rain

Togo and Benin

a) January Precipitation
   - GISS precipitation is an overestimate; again, rainfall only occurs along the coast
   - OSU is better, but still has too much precipitation in the north
   - GFDL is the wrong pattern

b) April Precipitation
   - GISS is too wet
   - OSU pattern is good, but has too little rainfall

c) July Precipitation
   - GISS is too noisy, with too little resolution
   - OSU is too dry, and the gradient is in the wrong direction
   - GFDL pattern is fairly good

d) October Precipitation
   - GISS does not show enough rain (October is the second maximum in rainfall pattern)
   - OSU pattern is okay, but rainfall is two times lower
   - GFDL pattern is wrong; ITCZ almost disappears over west Africa; rainfall is too low

Senegal

a) January Precipitation
   - GISS precipitation is an overestimate; no rain in Senegal, Guinea, etc.
   - OSU model is better with the correct pattern along the coast, but too much and too far inland
   - GFDL pattern is wrong; it should be a band, not a bullseye
b) April Precipitation
   - GISS is too wet
   - OSU pattern is not too good; it should be more zonal, with maximum coming inland
   - GFDL pattern and amounts are quite good

c) July Precipitation
   - GISS pattern is too noisy; the bulls-eye pattern is inaccurate
   - OSU pattern is wrong
   - GFDL pattern should stretch toward the west; the rainfall is okay

d) October Precipitation
   - GISS pattern is okay, but there is too much rainfall in the Sahel
   - OSU pattern is okay, and the amounts are fairly good
   - GFDL pattern is wrong; ITCZ (InterTropical Convergence Zone) almost disappears over west Africa;
     the rainfall is too low

Kenya

a) January Precipitation
   - GISS is an overestimate; there is no rain in the country during January
   - OSU pattern is fairly good; the actual amounts may be high
   - GFDL is wrong; it has the entire country wet, not dry

b) April Precipitation
   - GISS is too wet, and the pattern lies too far to the north
   - OSU model pattern is okay but is too wet
   - GFDL pattern is quite good; not sure of amounts

c) July Precipitation
   - GISS pattern looks okay in east Africa
   - OSU pattern is wrong
   - GFDL pattern is too wet in the south; it should be farther north

d) October Precipitation
   - GISS pattern is good; it shows the second maximum in rainfall
   - OSU pattern is wrong; it should have more rain
   - GFDL pattern is good
ECOLOGICAL EFFECTS WORKING GROUP

Co-Chairmen: M. Acevedo, E. Bonkoungou
Rapporteur: M. Coughenour
Members: K. Koulekey, J. Menyonga, A. Ndiaye, Y. Prevost, Y. Sangare, E. Wangari

INTRODUCTION

Tasks for the Ecological Working Group:

• Selection of study sites or regions. Sites will be selected within two ecological zones:
  1) humid forests, including coastal, rain forest and East African highlands; and
  2) arid and semi-arid grasslands and savannas.

Primary criteria for site selection will include representativeness of the ecosystems, the adequacy of the present ecological and climatological data bases, and the availability or presence of interested researchers and scientists.

• Characterize the stresses of interest that the ecosystems will be subjected to with respect to climate change.

• Examine the methodologies to be used, such as: models, paleoecological data bases, life zones, and scaling.

• Data acquisition procedures, and the individuals, institutions, and the formation of information networks will be discussed.

• Discussion of proposals to obtain added funding to conduct the research.

SITE SELECTION

The criteria for site selection were evaluated, and agreed upon. It was decided that the easiest way to proceed was to generate a list of sites that were most likely to satisfy criteria of data bases and researchers, then to evaluate their ecological representativeness (Table 2). Five arid/semi-arid sites plus the Turkana site were selected from the arid list, primarily based upon the existence of facilities and accessibility. These were Niamey, Oursi, Ferlo, Maroua, and Lamto. Turkana was considered to be more of a collaborative project with less competition for funds. The humid zone Mayobe site was given a reduced priority due to its recent establishment.

EXAMINATION OF STRESS CRITERIA

Arid and Semi-Arid Zones

Precipitation and the resultant soil water balance are of primary concern in this region. Soil water holding capacity will modify the responses to changes in rainfall, so this must be considered. The temporal distribution of rainfall within a year may determine the distribution among annuals and perennial plant species. It is particularly important to know whether there is unimodal or bimodal rainfall distribution and whether rainfall occurs in pulses or is distributed over time. The effects of human activities on soil properties and vegetation must be considered because these will modify climate response. The length and the frequency of drought periods were considered to be particularly important in arid zones.
Humid Zones

In the humid zones, precipitation changes will also be more important than temperature changes. While forests are less water-limited for primary production, species may be more sensitive to periods of water stress. Thus, changes in rainfall could result in species composition changes. In forested areas, wind is also an important variable as it is responsible for the creation of tree fall gaps and larger disturbances that affect succession and changes in species composition over time. An excess of rainfall could lead to changes in forested areas, as flooding results in waterlogged soils to which some species are not well adapted. Some forested areas occur at high elevations where cool temperatures may limit growth and where frost belts limit some species. Migratory bird species may be impacted by climate changes in temperate zones as well as in the tropical forests. Coastal ecosystems are impacted by changes in marine ecosystems, as terrestrial organisms feed on fish and other marine organisms. Coastal, lagoon, and estuarine ecosystems are particularly sensitive to sea-level rise and may be sensitive to UV-B effects.

Responses

The primary stress response variables would include: primary production, tree cover, species changes and diversity, and long-term self-sustainability of the ecosystem. Primary emphasis would be placed on direct plant responses, while indirect faunal responses to changes in habitat and food availability would follow from these. Faunal changes would include secondary productivity, population levels, species composition, and diversity.

METHODOLOGY

The identification of current and past distributions of species and correlation of these with climate variables was agreed to be a necessary first task. The study of current observed spatial gradients in climate and vegetation which would provide an empirical basis for predicting possible temporal climate and vegetation change would be useful. Apparently, a Holdridge or other analysis relating climate to vegetation physiognomy has not yet been performed for most of Africa. The use of both empirical classification and of process modeling were encouraged. The use of Holdridge life zones or similar ordination with climatic variables was seen as the more readily available methodology, which could be applied in the shortest time frame with the existing data. The empirical or correlative approach may also be less subject to the concerns that process models may be inaccurate or inappropriately parameterized for the PAN-EARTH sites. However, process modeling was accepted as a valid and necessary tool over the longer time frame.

Two options exist: either to use existing models or to develop a new model. The development of a new model was proposed as being a useful exercise that would unite the efforts of various organizations, and would more likely foster a consensus on results. Such a model would have to be simplified in form.
Such a model may be construed as being preliminary, with options for later expansion.

Use of common models, methodologies, and analyses among all involved sites would be desirable. This would provide a common language for larger-scale analyses, and it would be a mechanism to divide labor among organizations. Thus, the efforts of diverse institutions would together form a common and more robust analysis. For modeling exercises to be most productive, stresses that are expected to result from climate change will have to be identified beforehand in a more precise manner.

Scaling problems were discussed. It was agreed that the spatial scale of the analyses may have to vary in relation to the steepness of climatic gradients and the sensitivity of the system to change. It is likely that a finer scale of analysis will be required for savannas than for forests. The sizes of the study sites or areas were reviewed, in an effort to determine the scale of the anticipated analyses. This varied from the scale of regions, as in the extensive network of sites involved in ICRISAT and AGRHYMET based at Niamey, to the scale of 200 x 200km for an intensive ecological investigation, such as the Turkana project. The scale of the Niamey networks are defined by the extent of the Sahelian zone, especially areas where millet, sorghum, and cowpeas are grown.

The possibility of using paleobotanical studies such as from lake sediments was discussed. It was agreed that such studies would be useful in relating past vegetation responses to past climate change. The number of such studies is very limited in Africa, however.

The identification of existing spatial data bases is very important. For example, the FAO has just completed a vegetation map for the African continent that may be quite useful. FAO also has a soils map that would have great utility. It was noted that soils maps and data must be interpreted carefully because of the differences between agricultural and natural soils.

INSTITUTIONAL RELATIONS AND PROJECT ORGANIZATION

SAFGRAD was proposed as the overall coordinating body for the project. While SAFGRAD has good capabilities in arid and semiarid zones, it would require further strength in the humid zones.

Sites were discussed individually to identify the institutions and organizations that are actually involved. At each site there should be a contact person for ecological studies. The list of sites, organizations and some of the contact individuals are:

Niamey: ICRISAT, AGRHYMET
  Ferlo: ISRA, CSE, ORSTOM - Contact: M. Diagne, Ministry of Rural Development
  Maroua: IRA - Contact: Send to IRA Director in Yaounde, attention M. Eyog
  Oursi: IRBET, ISN-IDR, INERA - Contact: E. Bonkoungou

Turkana - Colorado State University, Natural Resource Ecology Laboratory - Contact: J.E. Ellis, D.M. Swift, and M.B. Coughenour. Also in Kenya, KRI, KREMU and KARI are likely to be the pertinent organizations.
Lamto: Faculty of Science, University of Abidjan - Contact: R. Vuattoux
Tai: Institute for Tropical Ecology, Dutch and Swiss Research Centers - Contact: Y. Sangare
Makokou: IRET - Contact: P. Posso
Moguga: EAFRO - Contact: Director
Yaounde: Faculty of Science, IRA - Contact: Chief of Forestry Research, IRA

PROPOSALS

Proposals to obtain funding for research on ecological effects from climate change should include the following topics:

- The problem of desertification must be examined. Certain proposals need to emphasize productive potential rather than desertification concepts. Others should retain reference to desertification.

- Support for remote sensing data and analyses (air photo and satellite). Immediate acquisition and analyses of the data as they are acquired would be most desirable, which would require a ground reception station. Proposals should include support for computational facilities that support PC-based image processing, such as ERDAS.

- Support for geographic information systems (GIS), as a means of conducting regional-scale analyses, performing a data base function, and carrying out scale translations. This might include hardware, software, and training.

- Studies of fire distribution, and its relation to transhumance.

- Studies of rainfall variation and ecological responses, over both short- and long-term scales and over the region. Analyses of rainfall will be primarily the domain of meteorologists; however, close cooperation with ecologists will be desirable.

- Studies of soil water recharge, surface flows, and the rates of surface runoff.

- Studies of the dynamics of natural vegetation in terms of primary production and species composition.

- Ties to socio-economic issues.

Proposals might be directed to such organizations as Ford Foundation, UNEP, UNSO and UNDP. Most funding agencies would be especially interested in research proposals that emphasize the networking concept and methodology.

It was agreed that the first and most important task for participants in PAN-EARTH is to prepare sound proposals that are worthy of support. Identification of funding sources will follow from this.
# TABLE 2

## SITES PROPOSED FOR ECOLOGICAL EFFECTS STUDIES

Evaluated with respect to availability of ecological data, climatic data, researchers, historical research, agricultural overlap, and access and communications. Latitude and longitude of the sites are also given.

<table>
<thead>
<tr>
<th>Arid and Semi-Arid Zone</th>
<th>Ecol Data¹</th>
<th>Clim Data²</th>
<th>Res Avl³</th>
<th>Hist Res⁴</th>
<th>Agr Ovl⁵</th>
<th>Access &amp; Comm⁶</th>
<th>Lat - Long</th>
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<td>1. Niamey (Niger)</td>
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<td>y</td>
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<td>y</td>
<td>y</td>
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<td>16N 2W</td>
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<td>y</td>
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<td>16N 15W</td>
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<td>8N 5W</td>
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## Humid Zone

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<th>Lat - Long</th>
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<tr>
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<td>5N 6W</td>
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<td>y</td>
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<td>y</td>
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</tr>
</tbody>
</table>

y - yes, ? - unknown or uncertain, pst - pastoral, rec - recent

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¹ ecological data available
² climatological data available
³ researchers available
⁴ historical research available
⁵ agricultural overlap
⁶ access and communications available
AGRICULTURAL EFFECTS
WORKING GROUP

Co-Chairmen: G. Hoogenboom, T. Bezuneh
Rapporteur: C. Harwell
Members: A. Anam, W. Cropper, J. Ellis,
R.A.D. Jones, G. Kingma, I. Miranda, P. Nkwi,
D.M. Osofo, P.L. Sarr, M.V.K. Sivakumar, M.
Traoré, T. Urabe

INTRODUCTION
Tasks for the Agricultural Working Group:
- Site selection of specific agricultural systems; criteria include:
  1) representative of agricultural systems of interest;
  2) adequacy of agricultural database;
  3) adequacy of climatological database;
  4) interested researchers/governments; and
  5) proximity to selected ecological systems.
- Identify the stresses to examine and the important goals.
- Look at methodologies to be used for effects assessments:
  1) simulation models;
  2) statistical models;
  3) historical records;
  4) physiological data; and
  5) potential growth areas.
- Data acquisition, individuals, institutions, network formation:
  1) soil characteristics;
  2) meteorological characteristics;
  3) yields; and
  4) cultivars.
- Training on the crop models.
- Plans for analyses, assigning responsibilities, scheduling activities

SITE SELECTION

It was suggested that the researchers be identified first, then have them define their own sub-network, including reaching outside their own country to pull in scientists from other countries. Networks already exist organized around specific crops. Coordinators are to work out specific crop sites for each zone, within the countries listed below (Table 3). SAFGRAD will take the lead responsibility for contacting coordinators.

Crop Zones:
- Savanna
  - Sahel:
    - northern, <400mm rainfall/yr
    - southern, 400-700mm rainfall/yr
  - Sudan: 700-1100mm rainfall/yr
  - Guinea: >1100mm rainfall/yr
  - Humid Coastal Zone
  - Eastern Africa

SAHEL SAVANNA

Major Crops: millet-cowpea systems; it was also suggested we include livestock (nomadic pastoral) systems.

Millet-cowpea

Coordinators: Millet: Dr. Oumar Niangado (Mali), head of the millet network for west Africa; and Dr. M.V.K. Sivakumar (Niger).
Cowpea: Dr. Cisse (Senegal), a member of the
steering committee; Institute for Agricultural Research, in Zaria, Nigeria; and IITA.

**Major Producers/Potential Sites:** Niger, Mali, Senegal, Nigeria, Burkina Faso

**Agro-climatology:** ICRISAT and AGRHYMET can provide climate information; both centers cover all of the Sahel, including eight-nine countries. Dr. Sivakumar has volunteered data for millet. CILS, the interstate committee for the fight against drought/desertification, is based in the Sahel, but data collection goes beyond the Sahel to include all of western and central Africa. Dr. Shrikart Jagtap, a researcher from the University of Florida, has recently moved to IITA as an agroclimatologist; he has worked with IBSNAT at UF before.

**SUDAN SAVANNA**

Major Crops: sorghum, maize, groundnuts

**Sorghum**

**Coordinator:** Dr. Moussa Traoré (Mali) will suggest the scientists; he is head of the sorghum network; there is a need to link also with ICRISAT, in Mali and Nigeria.

**Major Producers/Potential Sites:** Mali, Cameroon, Burkina Faso, Nigeria

**Maize**

**Coordinator:** Dr. Charles Thé, Institute of Agricultural Research, Cameroon; also IITA.

**Major Producers/Potential Sites:** Ghana, Togo, Cameroon, Benin, Nigeria, Côte d'Ivoire, Zaire

**Groundnuts**

**Coordinator:** Dr. Ba (Senegal), with ISRA and ICRISAT.

**Major Producers/Potential Sites:** Senegal, The Gambia, Mali, Guinea-Bissau

**Agroclimatology:** The agroclimatology coordinator for all of the region will be Dr. Joseph Owonubi (Nigeria). Dr. Shrikart Jagtap at IITA will also be contacted.

**GUINEA SAVANNA**

Major Crops: maize, rice, root and tubers (cassava, yam, etc.)

**Maize**

**Coordinator:** Dr. Charles Thé (Cameroon);

there is only one major network.

**Major Producers/Potential Sites:** Ghana, Nigeria, Cameroon, Benin, Côte d’Ivoire

**Rice**

**Coordinator:** Dr. R.A.D. Jones (Sierra Leone) will be the rice coordinator; he will coordinate with WARDA.

**Major Producers/Potential Sites:** irrigated rice: Senegal, Côte d'Ivoire; upland rice: Sierra Leone, Liberia; floating rice: Mali; mangrove: Guinea-Bissau

**Agroclimatologist:** with West Africa Rice Development Association (WARDA), Sierra Leone, and Côte d'Ivoire

**Root and Tuber Crops**

**Coordinator:** SAFGRAD and IITA are to identify the coordinator. Dr. Ottoo at IITA (Nigeria) is the contact for cassava.
**Major Producers/Potential Sites:** Zaire, Nigeria, Cameroon (the University of Maryland-Eastern Shore project), Ghana

**Agroclimatology:** contact IITA

**HUMID COASTAL ZONE**

Major Crops: plantain and banana, coffee, cocoa, oil palm; also fisheries

*Plantain/Banana*

**Coordinator:** Dr. Taye Bezuneh, SAFGRAD (Burkina Faso) will investigate this question.

**Major Producers/Potential Sites:** Ghana, Togo, Uganda, Nigeria

*Oil Palm*

**Coordinator:** Dr. Kanga; he is in charge of the oil palm program in Cameroon, at the Institute of Agronomy.

**Major Producers/Potential Sites:** Côte d'Ivoire, Cameroon, Nigeria, Zaire

*Coffee*

**Coordinator:** Dr. Coulibaly Nanga, at IRCC (Institute of Research for Coffee and Cocoa), Bingerville, Côte d'Ivoire; also the Inter-African Coffee Association, headquartered in Côte d'Ivoire. Dr. Awemo in Cameroon can also be a resource person.

**Major Producers/Potential Sites:** Côte d'Ivoire

*Cocoa*

**Coordinator:** Ghana has a special institute for cocoa development, and a coordinator will be sought there.

**Major Producers/Potential Sites:** Côte d'Ivoire, Ghana, Sierra Leone

**Fisheries**

The major issue here is sea-level rise and other indirect (climate/human interactions) impacts. This category may not be included in the final selections.

**Coordinator:** There is a fisheries research station in Cameroon. Dr. Njock in Cameroon may help with coordination.

**Major Producers/Potential Sites:** Cameroon, Senegal, Sierra Leone, Ghana, Mauritania, Côte d'Ivoire

*Coastal agroclimatology:* Dr. Nestor Aho (Togo).

**EASTERN AFRICA**

Major Crops: maize, sorghum, millet, teff, wheat, coffee, rice

*Maize*

**Coordinator:** Dr. Brhane Gebrekidan (Kenya).

**Major Producers/Potential Sites:** Kenya, Tanzania, Ethiopia

*Sorghum*

**Coordinator:** Dr. Vartan Guiragossian, ICRISAT/SAFGRAD coordinator for eastern Africa, located in Nairobi, Kenya.

**Major Producers/Potential Sites:** Sudan, Tanzania, Ethiopia, Uganda

*Millet*

**Coordinator:** Dr. Vartan Guiragossian will involve other national scientists

**Major Producers/Potential Sites:** Kenya, Uganda, Sudan


**Teff**

**Coordinator:** Dr. Saifu, with the Institute of Agricultural Research (IAR) in Addis Ababa, Ethiopia.

**Major Producer/Potential Site:** Ethiopia

**Wheat**

**Coordinator:** Dr. Tesfaye Tesemma, with IAR in Addis Ababa, Ethiopia.

**Major Producers/Potential Sites:** Ethiopia, Kenya

**Coffee**

**Major Producers/Potential Sites:** Kenya, Ethiopia

**Agro-climatology for region:** Dr. Naju (Kenya); Dr. J.O. Odak (Kenya); there is a regional remote sensing center in Kenya also; also perhaps CIAT in Kenya.

**SOCIAL SCIENCES**

The social science coordinator for all countries will be Dr. Paul Nchoji Nkwi (Cameroon). He will compile a list of interested researchers in various countries where there are agricultural sites and he will contact these persons to obtain their cooperation.

**STRESSES**

- Precipitation: The climatologists will produce algorithms for taking historical weather data and calculating future climate change. This will tell how the precipitation onset date and the total amount of precipitation may be changed. For the greenhouse effect, there is expected to be a precipitation increase, with earlier onset and more total precipitation; for nuclear winter scenarios, a suppression of precipitation is expected.
  - Temperature: For temperature, we expect to be given a range of a few degrees increase/decrease, applied uniformly.
    - Monsoon shift
    - Sea-level rise
    - Decreased insolation from increased precipitation and storminess
    - Drought stress with nuclear winter scenarios.

**CROP VARIABLES**

Important crop variables for greenhouse effect and nuclear winter:

- precipitation (rainfall): timing and amount (onset of rainy season, frequency, duration, pH); monsoon shift, duration
  - air temperature: maximum, minimum, and range
    - atmospheric gases: CO₂ increase, CH₄
    - solar radiation (energy and PAR and net): intensity, duration, wave length
    - harmattan effects: cloudiness, wind velocity, duration, intensity
    - wind: found by sensitivity analyses of crop models; frequency, speed, direction, storm duration
  - soils: temperature (max, min, range); water (available/extractable, runoff, drainage); salinity; pH; toxicity; fertility (N, P; native and applied); soil type; erosion (wind, water); flooding; microorganisms
  - VPD (vapor pressure deficit)
• pests: insects (locusts); animals (damage and control)
• diseases: damage and control
• weeds: damage and control
• farm inputs/management: crop selection, cultivars, planting date, spacing, irrigation; fertilizer; labor and traction (human and animal).

Not all parameters will be analyzed for every crop in every location; for each zone and crop, the coordinator and researchers can change the priority order and eliminate some items. The list is intended to be comprehensive, not exhaustive.

METHODOLOGIES
Suggested methodologies include:
• examination of available historical data;
• review of physiological data with special emphasis on stress responses;
• statistical models;
• simulation models;
• sensitivity of potential growth areas to climate change; and
• expert judgment.

It was felt that there is a need to use multiple approaches to studying these sites and stresses, and that as many methodologies should be used for which there are available data and scientists.

TRAINING
• IBSNAT training workshop in 1990
• regional workshop in Africa, training session after that; use available IBSNAT/DSSAT models, bring in other crop models if available; test and modify currently unreleased models
• other training sessions, small-scale, getting funding from existing institutional sources (SAFGRAD, ICRISAT, etc.) and seek outside donors for sessions.

SUGGESTED SCHEDULE OF ACTIVITIES
immediate: contact coordinators--Taye Bezuneh; current workshop report; proposal writing and submission; employ coordinator's assistant (by January 1990)
before February 1990: mini-workshop for all project coordinators; Taye Bezuneh to coordinate place (Ouagadougou; Lomé, Togo; Niamey); identify needs for equipment
mid-1990: process equipment purchases; training workshop
<February 1991: data collection and analysis
mid-1991: evaluation workshop; interim progress reports
July 1991: assessment of further needs
<July 1992: additional data analysis
December 1992: symposium and final reports

PROPOSALS
• overall coordination; computer purchases; mini-workshops; training workshops; assistant coordinator; travel funds; overhead expenses; support to scientists for model development and calibration

SOURCES
• JICA, Sasagawa: Japan; US AID; European Community; Ford Foundation; IDRC--special environmental problems office in Nairobi; UNEP; UNDP; ADB/BAD; Corporation Suisse; SIDAR; agencies for basic scientific research, such as NSF.
<table>
<thead>
<tr>
<th>Country</th>
<th>millet</th>
<th>cowpea</th>
<th>sorghum</th>
<th>maize</th>
<th>groundnut</th>
<th>root/tuber</th>
<th>rice</th>
<th>plantain/banana</th>
<th>oil</th>
<th>coffee</th>
<th>cocoa</th>
<th>fisheries</th>
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RECOMMENDATIONS

Dr. R.A.D. Jones, National Agricultural Research Coordinator, Ministry of Agriculture, Natural Resources, and Forestry, Sierra Leone, presented Workshop Recommendations composed by members of an executive committee. The complete text of those Recommendations follows.

FINAL RECOMMENDATIONS

This workshop on global climate change effects on the sub-Saharan environment, held in Saly, Senegal,

ACCEPTING the following existing situations:

- significant climate change has occurred in sub-Saharan Africa over the past few decades;
- the sub-Saharan Africa environment is experiencing substantial degradation;
- there is a critical need for agricultural development in sub-Saharan Africa to keep pace with the very rapid population growth rate;

RECOGNIZING that global climate change in the next several decades is expected to be unprecedented in human history and will significantly affect all facets of agriculture and food production, forestry, environmental quality, the human quality of life, and sustainable development in sub-Saharan Africa as a consequence of increased stresses on an already difficult situation,

and FURTHER RECOGNIZING the urgent need to evaluate the nature and magnitude of potential environmental, agricultural, and human impacts of climate change in sub-Saharan Africa, and that such a scientific evaluation has not yet taken place, although the data and the methodologies presently exist to begin such an interdisciplinary assessment:

HEREBY ESTABLISHES the PAN-EARTH SUB-SAHARAN AFRICA COLLABORATIVE RESEARCH NETWORK, coordinated by OAU/SAFGRAD in cooperation with the international PAN-EARTH Project headquartered at Cornell University, USA,

and RECOMMENDS the following:

1) the establishment of a network of scientific activities among African scientists and international collaborators, including environmental, ecological, agricultural, climatological, and social scientists, to identify the vulnerable ecological and agricultural systems of concern in sub-Saharan Africa and to conduct assessments of climate change and its impacts on humans and the environment;

2) the improvement of the agricultural, ecological, and climatological data bases for sub-Saharan Africa, including drawing upon existing data bases and research activities in national, regional, and international institutes and organizations;

3) that international and national organizations affiliated with the PAN-EARTH Sub-Saharan Africa Collaborative Research Network provide insofar as possible logistical and other support to these activities;
4) that existing training programs be strengthened and new training programs be developed within international, national, and other appropriate organizations to improve the scientific capabilities relevant to environmental issues, especially for collecting and analyzing data and conducting effects assessments;

5) that the additional, specific scientific recommendations included in the body of the PAN-EARTH Africa Workshop Report are implemented forthwith;

6) that a Pan-Africa conference be convened consisting of scientists and policy leaders from throughout sub-Saharan Africa on the topics of climate change, its effects on humans and the environment, and the policy implications, responses, and planning strategies for governments in the region;

7) that sub-Saharan African governments recognize the seriousness of the potential consequences of climate change on agricultural production, environmental degradation, and human impacts, and that these governments are called upon to provide concerted support to the network of scientific activities recommended herein to address global climate change impacts; such support should include field-level activities related to PAN-EARTH and affiliated activities, logistical support, encouraging scientists in research institutions to participate in the network of activities, and political support for these activities;

8) that the World Bank and African financial institutions, such as the African Development Bank and affiliated units, recognize the critical importance of climate change and environmental degradation in their long-term development projects; and

9) that the donor community, given their essential involvement in Africa for the promotion of agriculture and food production, restoration and protection of the environment, and initiatives towards sustainable development, provide support to the PAN-EARTH Sub-Saharan Africa Collaborative Research Network with whatever financial resources that can be brought to bear on these critical issues.
RECOMMANDATIONS FINALES

Cet atelier sur les effets des changements climatiques sur l'environnement Sub-Saharien tenu à Saly, Sénégal, en acceptant les situations existantes suivantes :

- un important changement climatique s'est produit en Afrique Sub-Saharienne au cours des quelques dernières décennies.
- l'environnement d'Afrique Sub-Saharienne subit une dégradation considérable.
- il s'avère impérieusement nécessaire que le développement agricole en Afrique Sub-Saharienne marche de pair avec le taux de croissance démographique très rapide.

EN RECONNAISSANT que le changement climatique du globe au cours des prochaines décennies est appelé à être sans précédent dans l'histoire de l'humanité et qu'il affectera significativement toutes les facettes de l'agriculture et la production vivrière, la forêsterie, la qualité de l'environnement, la qualité de vie des hommes et le développement soutenu en Afrique sub-Saharienne du fait des pressions accrues sur une situation déjà difficile.

ET EN RECONNAISSANT EN OUTRE qu'il est urgemment nécessaire d'évaluer la nature et l'importance des impacts environnementaux, agricoles et humains potentiels du changement climatique en Afrique Sub-Saharienne et qu'une telle évaluation scientifique n'a pas encore été faite bien qu'il existe présentement les données et les méthodologies permettant d'initier une évaluation interdisciplinaire.

CREE PAR LE PRESENT ACTE LE RESEAU PAN-EARTH DE RECHERCHE COOPERATIVE EN AFRIQUE SUB SAHARIENNE, coordonné par l'OUA/SAFGRAD en coopération avec le projet international PAN-EARTHD dont le siège se trouve à l'Université de Cornell aux USA.
ET RECOMMANDE ce qui suit :

1. Etablissement d'un réseau d'activités scientifiques entre les chercheurs africains et les collaborateurs internationaux comprenant des spécialistes de l'environnement, de l'écologie, de l'agriculture, de la climatologie et des sciences sociales afin d'identifier les systèmes écologiques et agricoles vulnérables faisant l'objet de préoccupation en Afrique Sub-Saharienne et déterminer les changements climatiques et leurs impacts sur les hommes et l'environnement.

2. Amélioration des bases de données agricoles, écologiques et climatologiques pour l'Afrique sub-Saharienne, y compris l'exploitation des bases de données et des activités de recherche existantes au niveau des instituts et organismes nationaux, régionaux et internationaux.

3. Que les organisations internationales et nationales affiliées au Réseau PAN-EARTH de Recherche Coopérative en Afrique Sub-Saharienne fournissent dans la mesure du possible un soutien logistique et autre à ces activités.

4. Que les programmes de formation existants soient renforcés et que de nouveaux programmes de formation soient créés au sein des organismes internationaux, nationaux appropriés et autres, en vue d'améliorer les capacités scientifiques relatives aux questions environnementales, particulièrement pour la collecte et l'analyse des données et pour l'évaluation des effets.

5. Que les autres recommandations scientifiques spécifiques incluses dans le Rapport de l'Atelier PAN-EARTH pour l'Afrique soient immédiatement mises en œuvre.

6. Qu'une conférence pan-africaine regroupant des chercheurs et des responsables politiques d'Afrique Sub-Saharienne soit organisée sur les thèmes des changements climatiques, de leurs effets sur les hommes et l'environnement, et des implications politiques, des réponses et stratégies de planification pour les gouvernements de la région.

7. Que les gouvernements d'Afrique Sub-Saharienne reconnaissent la gravité des conséquences potentielles des changements climatiques sur la production agricole; la dégradation de l'environnement, et les impacts sur l'homme et que ces gouvernements soient invités à assurer un soutien concerté au réseau d'activités scientifiques recommandé ici pour déterminer les impacts des changements climatiques du globe.
Ce soutien devrait comprendre des activités de terrain ayant trait au PAN-EARTH ainsi que des activités connexes, le soutien logistique, l'encouragement des chercheurs des institutions de recherche à participer au réseau d'activités et le soutien politique à ces activités.

8. Que la Banque Mondiale et les institutions financières africaines telles que la Banque Africaine de Développement et les entités qui y sont rattachées reconnaissent l'importance cruciale du changement climatique et de la dégradation de l'environnement dans leurs projets de développement de long terme.

9. Que la communauté des donateurs, compte tenu de leur engagement essentiel en Afrique pour la promotion de l'agriculture et de la production vivrière, la restauration et la protection de l'environnement et les initiatives en vue d'un développement soutenu, accorde au Réseau PAN-EARTH de recherche coopérative en Afrique Sub-Saharienne un soutien sous forme de ressources financières quelconques pouvant être mobilisées pour résoudre ces questions cruciales.
CLOSING REMARKS

Closing remarks were delivered by Dr. Taye Bezuneh, SAFGRAD Director of Research. A summary of those remarks follows:

Three areas of field activities were indicated during this workshop; the next step is to get results. The Cornell University PAN-EARTH Project has developed a general global project. As soon as we have a proposal for the Sub-Saharan Africa Case Study, we will send it out to potential sponsors, hopefully within a month. We need the workshop participants to give ideas about what is required for their own activities; it is urgent to complete the workshop report and proposal process as soon as possible. Whatever you send will be helpful to make the workshop report and proposals complete. We need the funding now; help us to assess your needs.

ADJOURNMENT

Dr. Mark Harwell delivered remarks of appreciation to Dr. Taye Bezuneh, Dr. Joseph Menyonga, their staff, and the translators. The strong progress on two fronts was noted:

1) identifying the critical issues of concern, and the systems that are needed to be focused on in sub-Saharan Africa for examining global change effects; substantial specific progress has been made in identifying ways to implement these studies over the next few years; and

2) on the organizational front, substantial progress has been made by formally establishing the PAN-EARTH Africa coordinating network and through the working groups' identifying people and institutions for this work, as a point of departure for actions in the future.

A complete workshop report will be ready in the near future, sent to all participants. Dr. Harwell added that we must also get on with the urgent task of preparing proposals. He emphasized here that there will be proposals to funding agencies for the overall coordination of the African research, a research assistant, future workshops and training, and for travel. Some exciting topics were identified at this workshop for proposals, but he called on the African scientists as they went home to come up with specific ideas for their own institutions, or for participation in collaboration with other institutions; then the Cornell PAN-EARTH unit will facilitate the development and submission of these proposals.

Dr. Messan Gnininvi, Solar Energy Laboratory, University of Benin, Togo, expressed thanks to SAFGRAD and his appreciation of the brotherly spirit developed at the workshop, especially in forming relationships among the many participants from around the world. He thanked his colleagues from Senegal for leaving their families and coming to share their lives; the workshop secretariat for all their logistical support; the translators; and the Novotel staff.

FINAL COMMUNIQUE

Dr. Paul Nchoji Nkwi, Scientific Technical Advisor, Ministry of Higher Education, Computer Services, and Scientific Research, Cameroon, presented the Final Communiqué to the workshop. The Final Communiqué, with corrections, was adopted by unanimous voice vote of the workshop participants. The complete French and English texts follow.
PAN-EARTH Sub-Saharan Africa Workshop
Final Communiqué

The PAN-EARTH Sub-Saharan Africa Workshop was held in Saly, Senegal, from 11-15 September 1989. The countries that took part in these important deliberations were: Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea-Bissau, Japan, Kenya, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo, United States, and Venezuela.

Certain international organizations also took part, such as: ICRISAT, OAU/SAFGRAD, PAN-EARTH Project, UNDP, UNESCO, and US AID.

We wish first of all to thank the President of Senegal, the government, and the people of Senegal for the warm reception we were given and the facilities that were offered to make this workshop a success.

We also thank the generous donors, most particularly: International Development and Research Centre/Canada, Ford Foundation, Rockefeller Brothers Fund, U.S. Agency for International Development, and the U.S. Environmental Protection Agency, which have given their financial assistance for the workshop's excellent organization.

After several days of reflection, the participants agreed to create the PAN-EARTH SUB-SAHARAN AFRICA COLLABORATIVE RESEARCH NETWORK on climatological changes, agriculture, and ecology, and appealed to African researchers to communicate to decision-makers and funding agencies the need to support this initiative.

Created in Saly, 15 September 1989.
Communiqué Final


Certaines organisations internationales y ont également participé, comme l'ICRISAT, l'OUA/SAFGRAD, le projet PAN-EARTH, le PNUD, l'UNESCO et l'US AID.

Nous voudrions tout d'abord remercier le Président du Sénégal, le gouvernement et le peuple du Sénégal pour l'accueil chaleureux qui nous a été réservé ainsi que pour les facilités offertes en vue du succès de cet atelier.

Nous remercions également les généreux donateurs et plus particulièrement le Centre Canadien de Recherche pour le Développement International, la Fondation Ford, le Fonds Rockefeller Brothers, l'Agence des États-Unis pour le Développement International, et l'Agence des États-Unis pour la Protection de l'Environnement qui ont apporté leur assistance financière pour l'excellente organisation de cet atelier.

Après plusieurs jours de réflexion, les participants ont convenu de créer le réseau PAN-EARTH de recherche coopérative en Afrique Sub-Saharienne sur les changements climatologiques, agricoles et écologiques et ont lancé un appel aux chercheurs africains afin qu'ils fassent comprendre aux décideurs et aux bailleurs de fonds la nécessité d'appuyer cette initiative.

Fait à Saly, le 15 Septembre 1989
APPENDIX A

PAPERS

GCM Greenhouse Warming Scenarios for Africa

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University of Maryland, College Park, Maryland 20742 USA

ABSTRACT

Global climate may change rapidly in the next century, and it is important to begin now to develop techniques to assess the impacts of this change on human activities. There are many problems associated with this endeavor, including defining the required climate information, and primitive, imperfect understanding of the course of future climate. Results of calculations of the effects of increasing greenhouse gases from general circulation models of the earth's atmosphere are presented. Suggestions are made as to how to produce scenarios for use in impact analysis in Africa, with an emphasis on multi-disciplinary teams.

1. Introduction

Many scientific studies warn of a rapid global climate change during the next century as a result of increased greenhouse gases in the atmosphere (National Research Council [NRC], 1979, 1983, 1987; World Meteorological Organization, 1986a, 1986b; the "State-of-the-Art" reports of the Department of Energy [MacCracken and Luther, 1985a, 1985b; NRC, 1985; Trabalka, 1985; Strain and Cure, 1985; White, 1985]; Ramanathan, 1988). They all suggest that the effects of greenhouse warming will become dominant over the natural variability of climate, including the effects of volcanic eruptions, ENSOs, internal circulation variations, and possible solar variations, and agree that surface air temperatures will rise, precipitation patterns will change and sea level will rise.

Even though these projections of the future are crude, it is important to begin now the assessment of the human impacts of these potential climate changes on a global basis, as has been done already for the United States (Smith and Tirpak, 1989). Because of the time lags inherent in the climate system, current actions will determine the future climate and hence, the human impacts. The results of current impact analysis, even if imperfect, will be useful in the design of future climate models to produce not just parameters of interest to atmospheric scientists, but parameters that will be needed by society, and in the design of technological responses to ameliorate the human impacts.

Although climate models simulate the entire globe and have fairly coarse resolution (typical grid spacing of 500 x 500 km), impacts are felt on local scales. This coarse resolution not only limits the ability of the models to produce valid simulations on a global scale, but it also makes it difficult to derive parameters on scales smaller than that of the models. And in order to study these impacts, scenarios which can be applied to many different activities and systems are needed. In this paper, the currently available climate model calculations for Africa are described. Samples of output from these calculations are presented in maps. These results will be useful as input for the generation of scenarios for case studies of the impact of climate change in Africa.

2. Defining the Required Information

In order to produce a scenario of future climate for use in impact analysis, it is first necessary to know the particular activity that will be impacted, and its sensitivity to different climate parameters. Only then can useful scenarios be provided that include
information on the important parameters with the appropriate temporal and spatial resolution.

Scenarios will be needed to study the impacts on a large number of systems that affect humans, including agriculture, forests, transportation, water resources, wetlands, human health, rivers, lakes, estuaries, biodiversity, coastal resources, air pollution, electricity demand, and societal and political systems. For each of these, the most important climate parameters in a world with a different climate may not well known. For instance, ocean currents, frequency and strength of oceanic storms, winds, frequency of fog, sea ice distribution and thickness, and sea level as it affects navigation in shallow straights and harbors will all be important for ocean transportation, while temperature, precipitation, cloudiness, CO₂ concentration, intensity of ultraviolet light, frequency of hail, and soil moisture will all be important for agriculture, although of different relative importance for different crops in different areas of the world at different times of the year. In addition, the frequency of rare, but extreme, events, such as hurricanes, drought, flooding, tornadoes, hailstorms, heat waves, and frost, may be more important than shifts in the mean of standard variables. And for each of the important parameters, the appropriate spatial and temporal distribution of the parameter must be provided. For example, the ocean currents may only be needed on a monthly basis in 1000 x 1000 km boxes, while temperature might be needed every hour at a specific location on a hillside near a coastline where a rice crop is being grown.

For many of the impacts, especially in agriculture, which is probably the most important one, since it directly affects the global food supply, the sensitivities are not well understood. Research is just beginning into the effects of changing different parameters and their distributions, either singly or in combination, on agricultural production. Therefore, it is very difficult at this time to specify the needed parameters, or their time or space resolution. Crop models are in their infancy, especially if they are expected to be applied in climatic regimes beyond our experience where nonlinear threshold effects may be important. And models of intermediate resolution, including fields or landscapes do not properly consider the very small scale or very large scale factors that may be important.

In all the above discussion another factor, technological change, has not been considered. The predominant factor in changes in virtually all the activities listed above in the past century has been technological improvements, not climate. It is not known how to predict future technological change and its interaction with climate. Furthermore, technological reaction to perceived climatic change, such as developing drought resistant seeds, or redirecting military resources to reforestation, may completely dominate future impacts. Societal reactions, such as mass migrations or revolutions, may also be more important than the direct effects of changing climate parameters on specific activities.

There are several possible methods to assess the impact of climate change, including actual field experiments under controlled conditions, simulation models, statistical models, studies of distributions of vegetation in current and past climates, and historical records of responses to weather and climate extremes. For each of these techniques, different types and resolutions of climatic information may be necessary in the scenarios.

In lieu of the results of research to answer all the questions addressed above, it is still possible to begin to address the sensitivities of small parts of this complex system in order to identify areas where research should be directed. Before it is possible to create detailed scenarios, it will be necessary to specify the priorities of impacts that will be addressed, and to find out from experts in these fields their best current judgment of the important parameters that will be needed, with the needed temporal and spatial resolution and the
most useful form of the information, such as statistical distributions or frequency of extreme events above or below certain thresholds.

3. Creating Climate Change Scenarios
Given that we can accomplish the steps discussed above, and that we have a long list of climate parameters that need to be specified in scenarios of the future, how can these scenarios be produced? One possibility is to use information from the recent instrumental record. Another potential technique is to use paleoclimatic information. The obvious tools to use are general circulation models (GCMs) of the earth’s atmosphere, but they also have many problems. Arbitrary scenarios, of changing parameters by specified fixed amounts, is another possibility.

Information from the Instrumental Record. Smith (1989) used the warm decade of 1930-1939 as an analog for a warmer future world. This method has three problems. First of all, the parameter used to choose this decade was global average surface air temperature, and many important climate parameters may have not been at their extreme values then. Secondly, it is now as warm as that decade in many parts of the world, and we would like to create scenarios of a climate quite different from the present one. And third, the 1930's probably were warm due to lack of volcanic aerosols for the preceding 2 decades, and it is now warm probably due to the compensating effects of cooling by volcanic aerosols, warming by more greenhouse gases, and the largest El Niño of the century (Robock, 1989). Superimposed on both of these time periods is the natural variability of climate, which was different in the different periods. So that using a different period with the same mean climate, but due to different causes, may produce an entirely different distribution of climate parameters and not be a good analog.

Paleoclimatic Information. The same problem as discussed above also applies to using paleoclimatic information. As shown by MacCracken et al.(1989), warm periods in the past were caused by different forcings than potential greenhouse-gas-induced warming and had different seasonal and latitudinal distributions of solar energy. Therefore they may be quite inappropriate to use for scenarios of the next century. One would expect quite different distributions of atmospheric circulation, precipitation, monsoons, and seasonal cycles produced by greenhouse gases as compared to Milankovitch forcing.

Scenarios From Climate Models. GCMs of the earth’s atmosphere have been used by 5 different groups (Oregon State University - OSU, National Center for Atmospheric Research - NCAR, Goddard Institute for Space Studies - GISS, Geophysical Fluid Dynamics Laboratory - GFDL, and the United Kingdom Meteorological Office - UKMO) to calculate how the global climate will change in response to doubling the CO₂ concentration in the earth’s atmosphere. These are called equilibrium calculations. The UKMO, OSU, GFDL, and GISS results are currently available at NCAR for analysis and use in generation of scenarios. Groups in the USSR, Australia, West Germany, and Canada are also doing equilibrium calculations. In addition, the GISS, GFDL, and NCAR models have been coupled to ocean models and used to calculate the time-dependent transient response of the climate system to gradual increase of greenhouse gases. The GISS transient calculations, made with a simplified, non-dynamic ocean model, are also currently available at NCAR. The GFDL and NCAR transient calculations were made with full oceanic GCMs, and therefore allow more possible modes of response.

The latest calculations that are generally available at NCAR are described in three appendices which are available by request to the Global Environment Program at Cornell University. Appendix A, by Dennis Joseph, lists the information currently available on tape, including the parameters available from each model. Appendix B, by Roy Jenne,
discusses in some detail the characteristics of the climate models used for these calculations. In Appendix C, sample maps from the currently available calculations are presented for Africa for the current climate and for the altered climate.

More calculations are always being done, and will become available in the future. For instance, GFDL has completed two more calculations that should be available within the next year: a higher resolution R30 2xCO\textsubscript{2} equilibrium calculation and the transient calculation with a full oceanic GCM.

Although these calculations have a coarse resolution and disagree on regional distributions of climate change, they can be used for creating ranges of scenarios for studying the impact of climate change. In order to create scenarios for individual locations, at least five related approaches have been recently suggested. Wigley et al. (1988) evaluated multiple linear regression techniques for calculating sub-grid-scale information. Turco (1988) suggested a method for using the seasonal cycle to scale the local changes from GCM output. Ackerman and Crock (1988) described a scheme to combine GCM output, local climatology, and expert judgment to create scenarios. Karl et al. (1989) developed a statistical technique employing empirical orthogonal functions to obtain local information. Smith (1989) has actually used simple procedures to create scenarios for United States impact studies, including 2xCO\textsubscript{2} GCM runs, and transient GCM runs.

Although GCMs give the best current picture of the climate of the future, and can be used to produce physically consistent scenarios, they still have large deficiencies in their ability to predict the future.

In the first place, it cannot be assumed that the climate will gradually warm, as is the implicit assumption in using a 2xCO\textsubscript{2} equilibrium simulation, or a smoothed transient simulation with only greenhouse gases for forcing and a simple mixed layer ocean, as in the GISS transient run. Even though the global climate has warmed during the past century (Jones et al., 1988), this warming may be entirely due to natural variations in the climate system, and totally unrelated to greenhouse gases (Robock, 1978; Lorenz, 1989). The amount of future climate change that will occur due to internal variation in the climate system is not now well known (Lorenz, 1989). Volcanic eruptions may play an important role in the future climate, depending on the frequency and amplitude of future eruptions (Robock, 1989). Although Hansen et al. (1988) include volcanic eruptions in some of their transient scenarios, these are just guesses as to the future level of volcanic activity. Cooling cannot be excluded from climate change scenarios for the next few decades, and must be considered in any set of scenarios.

In the second place, GCMs do not properly consider many important physical and biological processes. Clouds, soil hydrology, and ocean circulation, and the biological impact on the first two of these, are the major deficiencies that we can identify today. For example, when the UKMO included more realistic, but not necessarily more correct, cloud microphysical calculations in their 2xCO\textsubscript{2} experiments, the global sensitivity went from a 5.2°C warming to only 1.9°C warming (Mitchell, 1989). (It is the calculation with the 5.2°C sensitivity that is currently available for analysis.) When Manabe et al. (1989) at GFDL coupled an oceanic GCM to their atmospheric GCM in a transient experiment, they actually found cooling in the Southern Hemisphere (SH) as the Northern Hemisphere warmed. Even after a 200 year integration during which the atmospheric CO\textsubscript{2} concentration increased by a factor of 4, the air temperatures in the high latitudes of the SH failed to warm! Even if the system was warming everywhere, different parts of the climate system warm at different rates. Therefore, gradients will be set up and produce anomalous responses that cannot be seen in the equilibrium calculations. No greenhouse warming
calculations have yet included a biosphere model, yet recent calculations of Amazon deforestation (Nobre, personal communication) with the National Meteorological Center GCM coupled with the SiB biosphere model (Sellers et al., 1986) showed large effects of the biosphere on soil moisture and cloudiness. And this is with a very crude, GCM-grid-size biosphere model. How can GCM output be used to evaluate the effects of climate change on agriculture or forests, when the simulation did not include this biology in its calculations?

GCMs cannot even do a good job of reproducing the current climate (Grotch, 1988) due to the above problems and the resolution of the models. If they do not even include the necessary physics to satisfactorily simulate the current climate, how can we believe their simulations of altered climate?

The variability of climate may also change as the mean changes. Rind (1989) shows that in his simulations, as the climate warms the temperature variability decreases while the hydrological variability increases. Can the GCM model results be used to produce this aspect of the scenarios? Variability of the current climate is already very large, especially of the hydrological cycle, and we already know that extreme events, such as the 1988 midwestern US drought, hurricane Gilbert in 1988, or the Sahel drought, can have devastating effects on humans. Will the future climate actually be more variable than this?

Another aspect of climate variability is the scale of temporal and spatial variation. Do the models produce the correct variability for the current climate? How can sub-grid-scale variation be addressed? Will future climates be distinguishable from the present large variability on the local scale?

There are also advantages to using GCMs. They produce information for the entire world, and produce sets of parameters that are physically consistent, within the physics of the model. For instance, they do not produce increased precipitation and decreased cloudiness at the same time (unless, of course, the distribution of convective to layer cloudiness changed drastically). GCMs also produce results for specified causes of climate change, and different experiments can be set up to answer different research questions.

Arbitrary Scenarios. Guided by the results of the GCMs and the needs for the study of a particular impact, a climatologist could arbitrarily specify combinations of parameters that would be self-consistent and span the range of possible future climates. This could be the same for many different impacts, in order for all to study the same scenario, or could be tailored to a specific impact, so that the sensitivities could be optimally determined.

4. Suggested Steps To Create Scenarios
In light of all the problems listed above, how can we create scenarios for the PAN-EARTH case studies? I think that it is obvious that although a long-term research program is necessary to produce credible scenarios of the actual future climate, we can begin now to develop the experience necessary for this work. This research must include specialists from a number of different disciplines working together, and we have the opportunity here to proceed with case studies.

In the short term, I do not think it is useful to apply sophisticated statistical techniques to current GCM output. I think the only practical method to produce useful scenarios on a short-term basis is to use multi-disciplinary teams to carry out the following steps:

• Identify specific activities for case studies of climate impact;
• Identify locations for the case studies;
• Identify the methods to be used for the impact analysis;
Specify the climate parameters with their required spatial and temporal resolution that will be needed; and
Use expert judgment of climatologists utilizing the outputs of GCMs and their knowledge of the climate and microclimate of the regions of the studies to produce a set of arbitrary, reasonable, simple scenarios of the required parameters, along the lines of the method suggested by Ackerman and Cropper (1988).

In this way, scenarios will be created that include all the required parameters with the required resolution. Since the object of our preliminary work is identification of sensitivities, not the prediction of the entire impact on humans of climate changes, the GCM results to date will be useful as guidance, but need not be perfect.

A long-term research program of improvement of GCMs as well as techniques of impact analysis will be the only way to definitively answer the question of the impact of climate change on humans.

5. Acknowledgments
I thank Bill Campbell for producing the maps in Appendix C (available by request to the Global Environment Program, Cornell University). This work was supported by the PAN-EARTH project of Cornell University and the Center for Global Change at the University of Maryland.

REFERENCES

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The Sustainability Issue

Sustainability as global concern involves the complex interaction within and among nations and scientific disciplines. The causes and effects of deforestation, build up of CO2 and related gases (or warming up of the environment), ozone depletion transcend economic and geographic boundaries. Agriculture is both a contributor to erosion of sustainability and victim of other environmental abuses caused by rapid expansion of urbanization and industrial growth. Because of high demand of food, fuel, shelter and other related resources, an increasing number of countries suffer from deforestation, and increased aridity.

The productivity of the agricultural and ecological systems in sub-Saharan Africa can be sustained through optimum and efficient utilization of resources such as land, water, monitoring human activities and the climate. This can be attended through an interdisciplinary research network involving scientists and institutions of different research disciplines i.e. ecologists, agriculturists, climatologists, sociologists, etc.

Environmental degradation in Africa during the last three decades has been highly published but not yet critically characterized.

Modern agricultural production technology has raised the hope that hunger can be eliminated that carrying capacity of the land increased through better use of cubic volume of soil, water and air. The ecological sustainability and economic viability of Africa in general, and semi-arid regions in particular is threatened due to rising populations of human, animals with astronomical food, fodder and feed and needs exert pressure to destabilizing the agro-ecosystems.

One of the major causes for the continued decline of the environment in Africa is deforestation and poor land management. For example, cutting of trees to expand crop cultivation, for fuel and construction not only affected productivity by enhancing desertification but also induced ecological in balance. Studies

* Director of research SAFGRAD
by FAO and the World Resource Institute (in 37 countries) seem to
indicate that the plantation and deforestation ration 1:30.
Drought occurrence as repeated during the last two decades had a
dramatic effect on economy and sustainability of agriculture.
It has exacerbated desertification in particular and
environmental degradation in general. Climate change and its
effects has been evident in Africa for many decades. For example,
with increased desertification and aridity southward from
sahara. There has been general decrease of precipitation, by
about 15 to 35 percent would be reported by other participants.

This workshop that brought together scientists from
different nations would be the take off point to initiate Africa
case studies.

Objectives

The central objective of the network to be initiated in sub-
Saharan Africa would be to characterize the vulnerability of
African nations to global environmental change, and to ascertain
its critical importance on sustainable development in the region.
Some of the salient objectives of the network are:

a. To orient scientists and institutions in sub-Saharan Africa
to the apparent global climatic changes as they affect the
sustainability of the different agricultural and ecological
systems in Africa through case study analyses that would
be initiated in various countries of the region.

b. To improve scientific capabilities of scientists and
institutions of the region in order to make analysis and
characterization of the long-term climatic data base
available and relate such findings to apparent causes of the
African agrarian crises and ecological deteriorations.

c. Facilitate the exchange of technical information among
African countries on the development and application of
crop production models.

d. Study the effects of plausible climatic change scenarios
on the productivity and sustainability of agricultural and
ecological systems.

e. Through extensive sensitivity analyses identify the most
important climatic change with agricultural and ecological
effects in Africa, so that climate modelers can redirect
research to reduce uncertainties about those critical
factors.
Specific Objectives of this Workshop would be

- To initiate the Africa case study analyses
- To test physical/biological interface methodologies
- To plan and coordinate future case study activities

Focus

Pan-Earth Africa case study will focus on climate change, important for African situation i.e characterization and detail analysis of the climate in general as it relates to agricultural production and sustainability of ecological systems.

Research Areas

There would be three areas of research within the pan-Earth collaborative research networks to be initiated.

1. Climate change

   To study and analyse the physical and social aspects and effects of climate change.

2. Agriculture

   SAFGRAD affiliated crop commodity research networks need to assess the complexities of food production. Another major thrust of the Pan-Earth project would be to assist African scientists and institutions in developing appropriate agricultural models based primarily on USAID funded IBSNAT project, which has produced generic crop models for important crops i.e maize, sorghum, soy-bean, wheat, etc, would be utilized where available.

3. Ecology

   Range of ecological systems in sub-Saharan Africa, including the semi-arid region (i.e. the Sahel, Sudan and Northern Guinea savanna zones), and humid and sub-humid zones would be analyzed using statistical models and expert judgment. Effects on pasture land, and livestock, locust and other pest outbreaks, hydrology, dessertification and interaction with human interaction in the region will each receive appropriate attention.
Figure: The relation between deforestation and potential crop failure

Source: Goodland and Irvin (1975)
Some Criteria

- Ecological Zones
  1) savannas (Sahel, Sudan, Guinea)
  2) humid coastal zones (forest ecology)
  3) Eastern African highlands (dry land and lowland ecologies)

- Climatic Stresses
  1) change and shift of precipitation; drought
  2) temperature trends
  3) hydrological systems

- Biological Stresses and Human Activity
  1) population growth
  2) agricultural activity
     a) cereal-based agriculture
     b) nomadic and pastoral systems
     c) edaphic factors

- Data Bases and Availability of Researchers
EFFETS DES CHANGEMENTS CLIMATIQUES SUR LA PRODUCTION DU MIL ET DU SORGHO DANS LA ZONE SOUDANO-SAHELienne D’AFRIQUE DE L’OUEST.

Moussa Traoré, Agrophysiologiste, Institut d’Economie Rurale BP 258, Bamako - MALI.

INTRODUCTION

En Afrique de l’Ouest, notamment dans la zone Sahélienne, la sécheresse persiste depuis 1968 et maintient à un niveau très bas la production et la productivité des mil-sorgho, les deux cultures constituant la base de l’alimentation des populations de cette région. La tragédie humaine provoquée par cette sécheresse a amené huit (8) pays sahéliens à créer le Comité Inter-États de Lutte contre la Sécheresse dans le Sahel (C.I.L.S.S.) afin de chercher des solutions à court, moyen et long termes à ce problème. Il s’agit des pays suivants: Burkina Faso, Cap vert, Gambie, Mali, Mauritanie, Niger, Sénégal et Tchad.

D’après certains scientifiques, le phénomène de la sécheresse dans le Sahel serait lié aux événements de l’ENSO (El Nino Southern Oscillation), alors que d’autres l’attribueraient plutôt aux perturbations de la température de la surface de l’Océan Atlantique (Glantz, 1987). L’explication climatologique de cette sécheresse, devenue une donnée permanente de l’environnement sahélien, permettrait peut être d’en prédir l’occurrence, la période et l’intensité.
LA PLUVIOMETRIE DANS LE SAHEL

L'imprédicabilité de la quantité et plus importamment de la répartition dans le temps et dans l'espace de la pluviométrie dans les zones sujettes aux périodes de sécheresse intempestives constitue l'élément le plus aléatoire dans le cadre d'une démarche visant à en contrôler les effets. Les éléments majeurs influenceant le développement de la sécheresse (températures, radiations, vents et sols) sont plus stables pour un site donné.

En effet, au-delà de la réduction dans le cumul pluviométrique enregistré à travers le Sahel depuis vingt ans, la saison des pluies s'est plus ou moins raccourcie (de 2 à 3 semaines). L'installation des pluies est devenue hésitante et aléatoire provoquant ainsi des resemis à ne plus en finir et réduisant les surfaces effectivement emblavées.

Un autre phénomène observé dans le Sahel est le déplacement vers le Sud du tracé des courbes d'hysohîtes de l'ordre de 200 à 300 kilomètres par rapport aux moyennes 1951-80 (Puech, 1983).

Enfin, l'arrêt précoce des pluies assène un dernier coup à la production et à la productivité des cultures dans le Sahel. En effet, une sécheresse survenant pendant la phase de maturation des grains cause des cas d'avortement réduisant le nombre de grains par unité de surface, et en plus ne permet pas un bon remplissage des grains, d'où la baisse de rendement et de la production.

LES EFFETS DE LA SÉCHERESSE SUR LES MIL-SORGHO

La sécheresse a un impact sur les superficies emblavées quand elle survient en début d'hivernage. Le manque des pluies, en début de campagne, retardre et réduit la préparation des terres. Les semis deviennent aléatoires, multiples échecs sont enregistrés dans l'installation des cultures forçant les paysans à procéder à des resemis, et réduisant le nombre de plants à l'unité de surface, une composante importante du rendement. Au-delà d'une certaine date, il ne sert plus à rien de continuer à semer, d'où une réduction des emblavements par rapport aux prévisions. Ainsi, même si la quantité de pluies cumulées par la suite dépasse la normale, ce manque à gagner en superficie ne peut plus être rattrapé.

Des périodes de sécheresse peuvent survenir dues à la mauvaise répartition des pluies, s'ensuit un épuisement des réserves en eau du sol en cours de végétation, privant les plantes de la nécessaire transpiration pour leur survie, bien que le cumul total soit normal. Ces dernières années, la tendance pluviométrique a été à la baisse au Sahel, en plus de la mauvaise répartition. Ajouter à cela le raccourcissement
de la saison des pluies, et il devient impératif de procéder à un réajustement des cycles, dates de semis, degrés de résistance à la sécheresse, etc...

L’irrégularité des pluies dans le temps et dans l’espace, rend, cependant ce réajustement difficile. En effet, deux stations distantes de seulement quelques kilomètres peuvent cumuler des pluviométries totalement différentes, et ceci devient encore plus vrai au fur-et-à mesure que l’on s’avance vers le désert du Sahara. Une solution qui consiste à mettre au point des variétés plus précoces pour mieux cibler une zone donnée, reste de ce fait, difficile puisque à une distance dé 20 km la variété pourrait avoir des problèmes de moisissures des grains, et d’autres prédateurs.

Devant cette situation, il convient de considérer la sécheresse comme une donnée permanente dans la sous-région, et de promouvoir les recherches et actions nécessaires, en vue d’en contrôler les effets. Le développement de variétés résistantes à la sécheresse, la mise au point de techniques de prédiction et de contrôle pour en minimiser les effets sont des programmes à renforcer dans les différentes zones.


Au Mali, 65 à 70% des superficies cultivées le sont en mil-sorgho dont la moitié, à peu-près, est produite dans la zone Sahélienne des Régions de Ségu (30%) et Mopti (20%), (Statistique de base, 1989).

Le tableau N° 1 donne une estimation des productions, rendements et pluviométries dans les différentes régions du Mali pour la période 1974-88. Il en ressort une stagnation générale des niveaux de production, avec des chutes terribles les années de sévérité du problème devenu endémique de la sécheresse. Les rendements sont très fluctuants, également. Les corrélations ne sont pas bonnes par contre entre les différents éléments estimés, dénotant le besoin d’une amélioration des systèmes de collecte des statistiques.
REFERENCES


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ÉTUDE DE L'ISOMÉTRE 100 MM (LIMITE THÉORIQUE DU DESERT)
EVOLUTION DU CLIMAT

Relation Production Agricole et Evolution de la Pluviosité
dans le Sud Forestier Ivoirien

Rapport présenté par :

Mr. SANGARE Yaya,
Chargé de recherches
Institut d'Ecologie Tropicale
08 B. P. 109 ABIDJAN 08
(Rep. de Côte d'Ivoire)

Document Côte d'Ivoire
A - APÉRCU GÉNÉRAL

I - Position géographique

Située en Afrique de l'Ouest, le long du golfe de Guinée, entre 40°20 et 10°50 de latitude Nord, la Côte d'Ivoire s'étend sur une superficie de 322 500 Km², soit 1 % du continent Africain. (Fig. 1)

La Côte d'Ivoire est entourée par le Libéria et la Guinée à l'Ouest, le Mali et le Burkina Faso au Nord, le Ghana à l'Est et l'Océan Atlantique au Sud. Le pays a une configuration massive, en forme de quadrilatère d'environ 650 Km de côté. Il offre l'aspect d'un plateau uniforme s'élevant lentement du Sud au Nord jusqu'à une altitude d'environ 400 mètres. Le relief se concentre dans la zone occidentale du pays avec des collines atteignant 900 mètres d'altitude. Le Mont Nimba au Nord-Ouest du pays, avec 1 752 mètres est le point le plus éle-vé.

Le pays est irrigué par quatre fleuves principaux de direction Nord-Sud.

* Le Bandama, entièrement ivoirien, de 950 Km de long, traverse le pays en son milieu et se jette dans l'Océan Atlantique à Grand-Lahou. Au centre du pays, à Kossou, un barrage a été construit sur le Bandama. Ses affluents sont la Marahoué et le N'zi.

* LaComoé, de 900 Km de long, coule au Sud pour se jeter dans l'Océan, en suivant le tracé du cordon littoral au niveau de Grand-Bassam.

* Le Sassandra, de 650 Km de long, prend sa source en Guinée et coule d'Ouest en Est. Il se jette dans l'Océan à Sassandra. Il a cinq affluents : le Tiemba, le Bafing, le N'zo, le Lobo et le Davo.

* Le Cavally, de 600 Km de long sert de frontière avec le Libéria sur la plus grande partie de son cours.

2 - Climat, végétation et flore

a) - Grossièrement, trois zones de climat déterminées par l'importance et la répartition des précipitations, partagent le pays (Fig. 2).

* Le climat sub-équatorial le long de la région côtière, caractérisé par des températures aux amplitudes faibles (variant de 25 à 30°C), un fort pourcen-tage d'humidité (de l’ordre de 80 à 90 %), et des précipitations abondantes, atteignant 2.100 mm à Abidjan et 2.500 mm à Tabou, réparties sur 140 jours. Cette zone connaît quatre saisons :

  . une saison sèche et chaude entrecoupée de quelques pluies de Décem-bre à Avril ;
  . une saison de "grandes pluies" de mai à juillet ;
  . une petite saison sèche en août et septembre ;
  . une petite saison de pluies en octobre et novembre.

* Le climat tropical humide, qui s'étend sur la zone forestière et le sud de la région des savanes, est caractérisé par des amplitudes de températures plus importantes que sur la zone côtière variant de 14 à 33°C ; un pourcentage d'humi-dité atteignant 70 % et des pluies allant de 1.200 mm (à Bouaké) jusqu'à 2.300 mm
FIGURE I : LA CÔTE D'IVOIRE EN AFRIQUE

Source Société africaine d'édition
FIGURE 2 : ZONES CLIMATIQUES DE CÔTE D'IVOIRE
(à Danané). Cette zone connaît également quatre saisons : une saison de "grandes pluies" de juin à octobre ; une saison de "petites pluies" de mars à mai ; une grande et une petite saisons sèches de novembre à mars et de juillet à août.

* Le climat soudanais, qui s'étend sur la partie Sud de la zone des savanes, est caractérisé par des amplitudes thermiques quotidiennes et annuelles relativement importantes (de l'ordre de 20°C), une humidité nettement inférieure à celle du Sud du pays (de l'ordre de 40 à 50 %), et par la présence intermittente d'un vent frais et sec, l'harmattan, entre décembre et février. Cette zone de climat connaît deux saisons : une saison sèche de novembre à juin, avec quelques pluies en avril et une saison des pluies de juillet à octobre. Les précipitations peuvent atteindre 1.600 mm à Odienné et 1.000 mm à Bouna.

Une étude plus fine du climat ivoirien a été faite par ELDIN (1971) dans "Milieu Naturel en Côte d'Ivoire" : Mémoire ORSTOM n° 50 (Fig.3).

Le calcul des normes pluviométriques (période 1951-1980) du réseau pluviométrique (218 postes sur l'ensemble du territoire ivoirien) a permis de délimiter les isohyètes moyennes annuelles à travers tout le pays (Fig.4). Parallèlement les isothermes moyennes annuelles sur la période de 1961-1980 (Fig. 5) confirment que la température reste élevée à travers tout le pays.

b) - L'originalité de la flore ivoirienne dans le contexte afro-tropical est liée à l'existence d'un endémisme relativement important au niveau de la famille du genre et de l'espèce (AKÉ Assi 1984). Elle forme un ensemble hétérogène dans lequel coexistent deux flores différentes : l'une guinéo-congolaise ; l'autre soudano-zambezienne et, commune à l'une et à l'autre, "des espèces de liaison".

La limite des deux flores dans le territoire ivoirien a été tracée par GUILLAUMET et ADJANOHOUN (1971). Cette limite avec les frontières climatiques distinguent sur la carte de la végétation (Fig. 6) un domaine guinéen occupé essentiellement par les ensembles forestiers et un domaine soudanais occupé par la savane.

B - ÉVOLUTION DU CLIMAT

La climatologie d'une région est l'étude des données observées par le météorologue sur une période donnée. Pour les agronomes, exploitants agricoles, les conditions climatiques revêtent une importance quotidienne, car d'elles dépendent et les activités et la production. Les météorologistes dominent encore très mal le domaine de la prévision du temps, il s'agira donc pour l'agronome-chercheur de pallier les aléas climatiques, de tenir compte des contraintes climatiques pour améliorer le potentiel de production des spéculations agricoles. Pour la Côte d'Ivoire, l'étude des données météorologiques relevées depuis plusieurs décennies relève en effet une évolution plutôt défavorable.

Dans la zone intertropicale, en particulier en Côte d'Ivoire, la pluie est le facteur limitant essentiel de la production de nombreuses cultures. QUENCEZ (1986) traçant les courbes d'isodeficit hydrique moyen des décennies 1950-1959 ; 1960-1969 ; 1970-1979 et 1977-1986 pour la moitié Sud forestier de la Côte d'Ivoire (25 stations) a pu suivre l'évolution du déficit hydrique dans le Sud de la Côte d'Ivoire depuis 1950. Les différents graphiques (Fig.7) ont permis à l'auteur de faire les observations suivantes :

au cours des années 1950, le déficit hydrique moyen observé est inférieur à 300 mm sur toute la zone forestière, à l'exception d'une étroite bande sur le
DOMAINE SOUDANAIS

SECTEUR SOUDANAIS
Sevane boisée, arbuste ou arbustive et/ou forêt claire

SECTEUR SUB SOUDANAIS
Sevane boisée, arbustée ou arbustive et/ou forêt claire et forêt dense sèche

Ligne isotherme climatique cumulée (en mm)

Corrections apportées en fonction de la végétation naturelle par rapport au tracé initial

Zone climatique l'édicte climatique cumulée compris entre 150 et 250 mm

DOMAINE GUINEEN

SECTEUR MESOPHILE (forêt dense humide semi-décidue)
Sevane guineenne et forêt à Aucoumea klainei et Khaya senegalensis

SECTEUR OMBROPHILE (forêt basse sombre semi-décidue)
Type fondamental à Celtis spp. et Triplochiton scleroxylon et sa variété à Aesculus indica papaveracea et Khaya senegalensis

Type fondamental à Eucaliptus microcarpa et Diococcius monnieri type à Enterolobium treequum et Heterophyllum pseudolobus

Type à Diospyros spp. et Massonia sp.

Type à Uapaca sculentia, U. purpurea et Chidixia semiglyna et type à Termesia urpae et Chrysophyllum perevillicum

FIGURE 3 : CLIMATS ET VÉGÉTATION DE LA CÔTE D'IVOIRE

D'APRÈS ELDIN (1971).
FIG. 4 : PLUVIOMÉTRIE: ISOHYÈTES MOYENNES ANNUELLES 1951-1980

LÉGENDES:
PLUVIOMÉTRIE

1 COMPRIS ENTRE 900 ET 1100 MM
2 COMPRIS ENTRE 1100 ET 1200 MM
3 COMPRIS ENTRE 1200 ET 1300 MM
4 COMPRIS ENTRE 1300 ET 1400 MM
5 COMPRIS ENTRE 1400 ET 1600 MM
6 COMPRIS ENTRE 1600 ET 1800 MM
7 COMPRIS ENTRE 1800 ET 2000 MM
8 SUPÉRIEUR À 2000 MM
FIG. 5 : TEMPÉRATURES : ISOTHERMES MOYENNES ANNUELLES 1961-1980
FIGURE 6 : LES ZONES DE VÉGÉTATION EN CÔTE D’IVOIRE
littoral centre, incluant Grand-Lahou, Fresco. Une large zone à l'Ouest et une bande s'étendant jusqu'à Divo montrent un déficit inférieur à 200 mm. Les régions dont le déficit hydrique moyen était supérieur à 500 mm avant 1960 se situaient au Nord de la limite de la forêt sempervirente communément appelée V Baoulé.

Au cours des années 1960, le V Baoulé s'évase et pénètre légèrement vers le centre entre Lamto et Adzopé tandis que le littoral centre, de Sassandra à Grand-Lahou, voit son déficit passer à plus de 500 mm. Corrélativement, les surfaces subissant moins de 300 mm se réduisent et il ne reste qu'une bande entre Azaguié-Abidjan et Lakota-Oumé joignant les zones Est et Ouest. La zone comprise entre San-Pedro, Sassandra, le Sud de Soubre et Lakota voit son déficit croître au delà de 300 mm allant même jusqu'à 500 mm.

Au cours des années 1970, la zone à plus de 500 mm pénètre largement dans le Centre-Sud de la Côte d'Ivoire sur l'axe Lamto-Divo-Fresco tandis que les "limites" du V Baoulé descendent vers le Sud : l'isodéficit 400 mm. M'bahiatro et Béoumi connaissent maintenant un déficit moyen supérieur à 700 mm. L'autre fait très marquant est le reflux vers l'Est de la zone inférieure à 300 mm tandis que peu de changements interviennent à l'Ouest.

Enfin, au cours de la dernière décennie (en partie à cheval sur les années 1970), le couloir Nord-Sud de plus de 500 mm s'agrandit largement et fait place à une bande à plus de 600 mm ; la limite 500 mm descend vers le Sud-Est jusqu'à Azaguié. L'isodéficit 700 mm prend presque la place de l'isodéficit 600 mm dans le V Baoulé ; la zone inférieure à 300 mm est repoussée vers le Cavally et l'isodéficit 400 mm passe par San-Pedro et Soubré.

Les travaux de QUEENCEZ montrent qu'au cours des trente cinq dernières années, les conditions pluviométriques de la Côte d'Ivoire ont considérablement changé. A l'exception de la zone extrême Ouest et d'une zone au Sud-Est, le déficit hydrique moyen a augmenté de 200 à 400 mm dans le Sud ivoirien entre les années 1950 et aujourd'hui. Ce changement se traduit aussi par une grande fréquence des années à déficit très élevé - par le fait que chaque année "moyenne" a aussi un déficit plus élevé qu'au paravant - par la tendance à la disparition presque totale de la petite saison de pluie.

* L'étude poussée avec les données recueillies à la station de la ME (siège de IRHO/CI) (Graphique I) a permis à l'auteur de constater une croissance du déficit hydrique depuis les années 1950.

<table>
<thead>
<tr>
<th>Période</th>
<th>Déficit moyen (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950/1959</td>
<td>212</td>
</tr>
<tr>
<td>1960/1969</td>
<td>270</td>
</tr>
<tr>
<td>1970/1979</td>
<td>320</td>
</tr>
<tr>
<td>1977/1986</td>
<td>416</td>
</tr>
</tbody>
</table>

La moyenne du déficit hydrique sur 5 années (graphique I) montre qu'elle passe de 150 mm au cours des années 1930 (période la plus pluvieuse) à plus de 400 mm au cours des 5 dernières années. L'auteur n'a pu mettre en évidence les variations cycliques du déficit hydrique.

En conclusion, nous pouvons dire que globalement la Côte d'Ivoire a été de moins en moins arrosée ces trente dernières années. Si parmi les causes de cette évolution il y a la déforestation, les activités entreprises en Côte
Fig. 7 : ÉVOLUTION DU DéFICIT HYDRIQUE DANS LE SUD DE LA CÔTE D'IVOIRE DE 1950 À 1986

Courbes d'isodeficit hydrique moyen

Décanie 1950-1959

Décanie 1960-1969
FIG. 7 : (suite) : Courbes d'isodeficit hydrique moyen (Côte d'Ivoire).

Décennie 1970-1979

Décennie 1977-1986
d'Ivoire ne sont pas les seules à prendre en compte ; il s'agit d'un phénomène mondial dans lequel chaque nation devra apporter sa pierre pour la sauvegarde de l'environnement.

* Les conséquences agricoles de la réduction de l'alimentation hydrique des cultures sont très importantes (pour le palmier à huile, c'est une diminution de 4 t/ha que l'on observe quand le déficit hydrique moyen passe de 200 à 400 mm. QUEENCEZ (1986), il est donc nécessaire que les agronomes proposent aux planteurs des solutions adaptées pour réduire l'effet d'une réduction de la pluviosité : matériel végétal plus résistant à la sécheresse, aménagement des plantations propres à supprimer toute perte des eaux de pluie et à améliorer la retention de l'eau dans les sols.

C - INFLUENCE DU CLIMAT SUR LA PRODUCTION AGRICOLE

- Cas du palmier à huile (évolution de la pluviosité)


* Le climat favorable à l'élaeiculture est de type tropical ou équatorial humide. La pluviométrie constitue le facteur de production principal ; la normale, répartie en une ou deux saisons, des pluies doit être supérieure à 1,800 mm et le déficit hydrique moyen annuel ne doit pas dépasser 300 mm. Le palmier est une plante de soleil et d'eau, à croissance continue qui demande des conditions climatiques aussi constantes que possible tout au long de l'année. Parmi elles, l'alimentation en eau de la plante constitue le facteur de production le plus important.

A l'IRHO/CI l'évolution de la production au cours des années a été observée sur un essai mis en place en 1961. Pour expliquer les importantes variations annuelles, il a été tenté de mettre en corrélation la production et les différentes composantes du climat : pluviométrie, ensoleillement, déficit hydrique, hygrométrie, température. Le déficit hydrique est le paramètre qui joue le rôle le plus important.

Les observations ont conduit DUFOUR et COLL. (1988) à l'élaboration d'un modèle, Fig. 8 permettant d'estimer le rendement d'une année en observant les déficits hydriques calculés selon une méthode simplifiée (de la formule de Penman) pour l'Afrique de l'Ouest et qui ne prend en compte que la pluviométrie : nombre de jours et quantité en millimètres.

A l'échelle mensuelle, on prend en compte les précipitations (P), la consommation maximale de la culture (ETP), la réserve maximale utilisable du sol ($R_m$). Le bilan hydrique (B.H) mensuel simplifié s'établit :

$$B.H. = R_i + P - ETP$$

$R_i$ étant la réserve initiale au début du mois.

ETP est évaluée à 120 mm quand il y a plus de 10 jours de pluie et à 150 mm quand il y a moins de 10 jours de pluie et $R_m = 200$ mm pour le palmier
à huile.

Ce calcul peut être effectué sur différentes périodes (mois ou décade). Cette méthode est évidemment schématique mais donne des résultats qui ne s'écartent que raisonnablement des déficits hydriques réels tant qu'on se trouve dans les conditions de température, hygrométrie, ensoleillement moyens de l'Afrique de l'Ouest. Elle a de gros avantages d'être utilisable dans les zones où les données météorologiques sont très fragmentaires.

Les calculs de corrélation entre la production et le déficit hydrique cumulé (de moins de 30 mois avant la campagne à plus de 6 mois après la campagne) (Fig. 8) donnent une corrélation $r^2 = 0,90$ (Fig. 9).

Les différentes figures montrent donc une bonne liaison entre les précipitations et la production, le déficit hydrique joue un rôle primordial dans l'élaboration du rendement qu'il influence durant une période allant de 33 mois jusqu'à 6 mois environ avant la récolte. Le climat du 13ème au 6ème mois avant la maturité est prépondérant. Un stress hydrique important influence 6 mois plus tard sur la sexualité et se traduit par un avortement des jeunes inflorescences mâles.

En conclusion si le modèle du bilan hydrique fonctionne assez correctement, le rendement d'une plantation est lié à l'ensemble des paramètres climatiques - physiologie de la plante - fonctionnement du sol - techniques culturales toutes choses devant être intégrées pour l'établissement d'un modèle susceptible de prédire la production.
FIG. 3
Schéma prévisionnel de production annuelle (tonnes/ha) en fonction du déficit hydrique annuel moyen.

O. Dufour et Col. (1988) - Présentation d'une méthode simplifiée de prédiction de la production d'une plantation de palmiers à huile à partir de la climatologie. Oléagineux, Vol. 43, n°7.


Eldin (1971) - Le climat in Le Milieu Naturel de la Côte d'Ivoire. Mémoires ORSTOM n° 50.

AXE Assi (1986) - Flore de Côte d'Ivoire. Thèse Université d'Abidjan (Côte d'Ivoire).
EFFETS DES CHANGEMENTS CLIMATIQUES
SUR L'ECOLOGIE SAHELIENNE

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IRBET/BURKINA FASO

Note présentée à l'Atelier sur les "Effets des Changements climatiques sur les systèmes agricoles et écologiques d'Afrique subsaharienne"

Saly, Sénégal 11-14 Septembre 1989.
1. INTRODUCTION

L'espace géographique considéré pour la présente note est la partie sahélienne de l'Afrique de l'Ouest. Il s'agit, pour l'essentiel, des pays couverts par le Comité Permanent Inter États de Lutte Contre la Sècheresse dans le Sahel.

La structure et la dynamique des écosystèmes de cette région sont caractérisées par les principales contraintes suivantes du milieu physique et humain :

- pluviométrie insuffisante et aléatoire marquée par une extrême variabilité spatio-temporelle avec des épisodes de sécheresse sévères ;

- sols caractérisés par un faible niveau de fertilité naturelle et une grande fragilité structurelle qui les rendent facilement dégradables sous culture ;

- productions végétales et animales fréquemment décimées par des ennemis des cultures et des pathologies animales sévissant de façon plus ou moins endémiques ou avec des explosions épidémiques ;

- cadre humain marqué par les principales caractéristiques socio-démographiques et économiques suivantes : taux très élevé de l'accroissement démographique (2,5 à 3 %), inégale répartition spatiale de la population, importance des mouvements migratoires et de l'exode rural entraînant un accroissement urbain rapide, crise des systèmes traditionnels extensifs de production agro-sylvo-pastorale, etc.
L'augmentation de la pression démographique et la pénurie des conditions climatiques ont provoqué une dégradation du capital de ressources naturelles (eau, sol, pâturages, ressources forestières, faune sauvage) et sévèrement affecté les équilibres écologiques. La dégradation revêt des formes variables selon les conditions locales, mais on peut distinguer globalement deux aspects principaux :

- pour les pays du Sahel septentrional qui constituent en quelque sorte les pays du front de la sécheresse, la forme dominante est l'avancée des dunes, avec ensablement des points d'eau, des routes, des habitations humaines, etc.

- pour les zones méridionales plus humides, les aspects dominants de cette dégradation sont beaucoup plus marqués par l'impact des activités humaines : dégradation de la végétation naturelle réduite parfois à quelques lambeaux, formation d'auréoles déforestées autour des centres urbains, etc.

La présente note examine très brièvement quelques spécificités du climat et des écosystèmes sahéliens et dégage quelques éléments de réflexion sur l'impact des changements climatiques sur l'écologie sahélienne.

2. **SPÉCIFICITÉ DU CLIMAT SAHELIAN**

Une des principales caractéristiques du climat sahélien est sa pluviométrie insuffisante et aléatoire, fortement saisonnière, extrêmement variable dans l'espace et dans le temps, avec des averses de fortes intensités qui les rendent très érosives. Quelques uns de ces aspects sont illustrés ci-dessous.

2.1 **Microvariabilité spatiale de la pluviométrie**

Il est d'observation courante au Sahel que des sites voisins peuvent enregistrer des quantités de pluie très différentes. Par exemple, des écarts pouvant atteindre 40 % des précipitations annuelles ont été enregistrés au Burkina Faso entre pluviomètres distants seulement de 5km (Grouzis, 1988).
Au Niger, l'ICRISAT (1988) indique pour une même pluie, des enregistrements de 34 mm et 8,9 mm pour des pluviomètres distants de 3,2 km.

2.2. Forte intensité des pluies

Selon des observations de Charreau rapportées par Giffard (1974), la moitié des pluies annuelles tombent à Bambey (Sénégal) avec une intensité supérieure à 27 mm/heure. On enregistre chaque année des pluies d'intensité supérieure à 100 mm/heure. Des pluies d'intensité aussi forte sont très érosives. On est très loin des pluies des zones tempérées dont l'intensité est d'environ 2 mm/heure, même si cette moyenne masque des maxima parfois beaucoup plus importants, comme le souligne Giffard (op.cit.)

2.3. Variabilité temporelle

Selon Nicholson (1982), le coefficient de variation de la pluviométrie interannuelle serait de l'ordre de 15 à 20 % en zone soudano-guinéenne, et atteindrait 30 à 50 % en zone sahélienne. Une grande variabilité interannuelle de la pluviométrie n'est pas spécifique au sahel ; c'est une caractéristique générale de toutes les zones sèches du monde. Ce qui est par contre spécifique au sahel, c'est une tendance pour les années de pluviométrie excédentaire ou déficitaire à se succéder sur des périodes pouvant atteindre 10 ans et même beaucoup plus, émaillant ainsi l'histoire climatique de la région de décennies "anormalement" pluvieuses comme la décennie des années 50 ou "anormalement" sèches, comme l'épisode le plus récent commencé à la fin des années 60 et qui a duré près de deux décennies avec ses conséquences dramatiques bien connues.

Ce qu'il est important de retenir, c'est, comme l'a souligné Goudet (1984) la spécificité des zones sèches au sud du Sahara par rapport aux zones méditerranéennes et aux zones arides d'Amérique centrale et du sud. Il est important de tenir compte de cette spécificité pour éviter les écarts de l'extrapolation trop rapide de résultats obtenus dans d'autres zones arides du monde.
2. CARACTERISTIQUES DES ECOSYSTEMES SAHELiens

Comme dans beaucoup d'autres zones sèches du monde, la base structurelle de la production primaire dans les écosystèmes sahéliens est une formation mixte forestière et graminéenne appelée savane. Il existe plusieurs types de savanes en fonction de la densité et la taille des arbres et arbustes, mais selon Frost et al. (1986) les variables majeures qui déterminent la structure et le fonctionnement de ces savanes sont : l'eau du sol, les éléments nutritifs du sol, le broutage et pâturage par les animaux domestiques et la faune sauvage, les feux de brousse, et l'impact des activités humaines. Ce sont ces variables qui déterminent la dynamique et l'équilibre apparent dans lequel coexistent une composante ligneuse et une strate herbacée.

Dans les écosystèmes forestiers humides, on sait que les éléments nutritifs du sol sont stockés en grande partie dans la biomasse, et qu'un réseau efficace de microorganismes dans la rhizosphère capte les éléments libérés de la décomposition de la matière organique, et les recyle dans la production primaire, si bien que la plupart des éléments nutritifs sont recyclés sans passer dans le sous-compartment sol de l'écosystème. Un modèle explicatif aussi précis n'a malheureusement pas encore été mis au point pour le fonctionnement des écosystèmes sahéliens.

Malgré d'importantes études sur les contributions des herbacés et des ligneux à la biomasse et à la productivité des écosystèmes sahéliens, on comprend encore mal les parts respectives de ces sous-systèmes dans le flux d'énergie et dans les bilans d'eau et d'éléments nutritifs. De même, on connaît très mal leurs contributions relatives à des paramètres écologiques importants comme la résistance et la résilience des écosystèmes.

4. IMPACT DES CHANGEMENTS CLIMATIQUES SUR L'ECOLOGIE SAHELienne

En raison de la spécificité du climat sahélien qui peut comporter plusieurs années successives de pluviométrie déficitaire, l'impact direct du climat sur l'écologie sahélienne a eu des effets dramatiques bien connus : cimetières à bois couvrant de grandes étendues de brousses tigrées, tarissement de cours d'eau, mort de cheptel, etc.
Dans les écosystèmes sylvopastoraux du sahel septentrional, la productivité des pâturages herbacés qui dépend entièrement des pluies annuelles s'est sérieusement dégradée durant les récentes sécheresses. En plus de la dégradation de la productivité, les terres à pâturages connaissent également un rétrécissement de superficie aussi bien dans leurs parties septentrionales que méridionales.


Les aspects techniques de l'impact des changements climatiques sur l'écologie sahélienne ont été étudiés par de nombreux auteurs dont Grouzis (1988) qui a analysé de façon détaillée la structure, la productivité et la dynamique des systèmes écologiques sahéliens à partir d'un suivi rigoureux de la flore et de la végétation de la région de la mare d'Oursi au Burkina Faso. Cette étude décrit, entre autre, la structure de la végétation, la mise en place du peuplement (production de semences, établissement, etc.) et analyse aussi bien les systèmes épiphytes que les systèmes racinaires. L'étude précise en outre les conditions de la dégradation et les capacités de régénération des systèmes écologiques sahéliens.

Par rapport à la quantité des informations disponibles sur la végétation, l'écologie sahélienne souffre d'un manque notoire d'informations sur la production secondaire, contrairement aux nombreuses études effectuées sur ce thème en Afrique de l'Est. L'impact des changements climatiques sur les populations et communautés animales ne semble pas avoir fait l'objet d'études aussi approfondies que dans le cas de la végétation.

En plus de l'impact direct des changements climatiques, les parties méridionales du sahel subissent des dégradations qui résultent des effets conjugués de la sécheresse et de la pression anthropique (défrichements culturaux, coupe de bois, etc.).
Une des spécificités du sahel africain quand on le compare aux écosystèmes d'autres zones arides et semi-arides est l'ancienneté de la présence humaine. Frost et al (1986) rapportent les âges suivants pour la présence de l'homme dans les savanes de diverses parties du monde plus de 2 millions d'années pour l'Afrique, 1 million d'années environ pour l'Asie, 40 000 ans pour l'Australie, 25 000 ans pour l'Amérique du sud. Compte tenu de cette présence très ancienne de l'homme dans les savanes d'Afrique on ne peut pas comprendre la structure et la dynamique des écosystèmes sahéliens, encore moins promouvoir des actions réalistes de leur gestion si l'on tient compte uniquement des lois du milieu naturel sans prendre en compte l'action humaine.

Des études de mission aérienne et d'images satellites réalisées au cours des années 1950-1956 et comparées à des données plus récentes ont montré par exemple que dans la partie septentrionale du Burkina Faso par exemple, les surfaces cultivées ont augmenté de 44 % entre 1955 et 1975.

On sait que l'impact de l'augmentation de la population sur les défrichements agricoles se traduit à la fois par l'augmentation des superficies déboisées et une détérioration rapide de la fertilité des sols cultivés qui ne bénéficient plus de temps de repos.

Les prélèvements de bois pour le chauffage de divers services dépassent la capacité naturelle de régénération des forêts et provoquent des auréoles déboisées autour des centres urbains. Les diverses stratégies forestières de reboisement au sahel n'ont pas atteint les résultats escomptés, si bien qu'une proportion très importante de la consommation de bois continue d'être tirée de la végétation naturelle (Bonkoungou, 1987).
CONCLUSION ET PERSPECTIVES

La savane africaine connait une présence humaine très ancienne.

Pendant des millénaires, le sahelien a tiré de son environnement immédiat tout ce dont il avait besoin pour vivre. En raison de la faible pression démographique et du niveau élémentaire des technologies utilisées, les populations animales et végétales n'étaient pas menacées.

Aujourd'hui, une conjoncture de facteurs défavorables liés à la sécheresse et à un accroissement sans précédent de la population impose aux écosystèmes sahéliens des perturbations d'une intensité qui dépasse dans beaucoup de cas la capacité innée de résistance ou de résilience de ces écosystèmes.

Diverses expériences de mises en défens laissent à penser que les écosystèmes sahéliens possèdent de réelles capacités de régénération et une vitalité de la végétation qui se manifestent très rapidement durant les années de bonne pluviométrie. Faute de disposer d'informations scientifiques justes sur la dynamique de cette régénération, il est difficile de comprendre l'impact des changements climatiques et/ou de proposer des modèles de gestion appropriés.

Il devient urgent d'entreprendre une action régionale coordonnée à partir d'études de cas bien choisis.

Souhaitons vivement que le présent atelier puisse contribuer rapidement à cela !

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EFFET DES CHANGEMENTS CLIMATIQUES SUR L'ECOSYSTE ME COTIER
DU BENIN ET DU TOGO

Par

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RÉSUMÉ

La Côte bénino-togolaise est une enclave sèche et très peuplée du Golfe de Guinée où le balancement du Front Inter Tropical détermine la répartition des précipitations sur deux saisons d'importance inégale.

La pluviométrie annuelle subit d'importantes fluctuations décennales au sein de grandes oscillations climatiques dont on n'a que des témoignages et indices qui appellent une vérification objective, la phase actuelle correspondant à une séance climatique sèche.

L'étroite plaine côtière héberge une Mangrove particulière où les activités de production de sel de cuisine, très dépendantes des faits climatiques, menacent l'équilibre de l'écosystème. La Savane arbustive installée sur le plateau sédimentaire côtier est le siège d'intenses activités de production agricole à base de Maïs et de Manioc, activités pour lesquelles le cycle d'assèchement climatique en cours d'évolution dans la région a contraint les populations à opter pour des stratégies de subsistance discutables. Ces stratégies ont besoin d'être étayées par des bases scientifiques dont l'élaboration revient à la communauté internationale, en raison du caractère supra national des faits climatologiques.
EFFET DES CHANGEMENTS CLIMATIQUES SUR L'ECOSYSTEME COTIER DU BENIN ET DU TOGO

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Les changements climatiques ont considérablement marqué la vie sur notre planète, et l'histoire des systèmes biologiques se confond pratiquement avec celle du climat.

En effet, quel que soit leur niveau d'organisation, les entités vivantes doivent leur existence aux échanges continus d'énergie et de matière avec l'environnement, à travers un équilibre dynamique favorable. Tout changement au niveau des composantes de l'environnement entraîne la modification de l'équilibre et, par voie de conséquence, une réaction d'ajustement adaptatif des systèmes biologiques considérés.

L'évolution de la végétation tropicale africaine durant les quatorze derniers millénaires, appréhendée à travers l'études des diagrammes polliniques des principaux taxons représentés dans les sédiments du Lac Victoria datés par le dosage du $^{14}$C, offre un bel exemple de réponse adaptative des biocenoses aux oscillations climatiques (Leme, 1978). La période allant de -10 000 ans à -2 000 ans correspondait à une phase d'évolution où le couvert végétal était dominé par les Moracées et les Ulmaceées, notamment les Celtis de la forêt humide (fig.1). Elle est précédée d'une phase de savane à Poacées et Cypréacées sous climat sec. Dès le début de l'époque chrétienne, la végétation a retrouvé un stade de savane sous climat plus sec et plus chaud qui se poursuit encore aujourd'hui et que l'homme contribue, peut-être à maintenir encore très longtemps s'il ne prend davantage conscience de son rôle et de son intérêt à long terme dans la biosphère.

Dans le domaine de la climatologie, l'histoire technologique de l'humanité, qui ne remonte qu'à la fin du 18ème Siècle de l'ère chrétienne, est trop récente pour nous permettre de disposer d'enregistrements directs de grands changements climatiques et de leur effet sur les écosystèmes. Aussi, les oscillations climatiques accessibles aux mesures directes se limitent-elles aux oscillations décennales et inter annuelles, notamment dans les pays en développement où les séries de données accessibles couvrent moins d'un siècle d'enregistrement.
Fig. 1 - Diagramme pollenique des principaux taxons représentés dans les sédiments du Lac Victoria datés par le dosage du $^{14}$C (d'après KENDALL cité par LEMEE, 1978).

Fig. 2 - Données moyennes mensuelles de précipitations et d'évapotranspiration potentielle à Cotonou et à Lomé au cours de la période 1951 - 1980.
I. - RÉGIME CLIMATIQUE DE LA ZONE CÔTIÈRE DU BÉNIN ET DU TOGO

La zone côtière du Bénin et du Togo appartient au système côtier d'exposition Sud du Golfe de Guinée, de latitude comprise entre 6°N et 7°N, et soumis au balancement du Front Inter Tropical qui le traverse régulièrement deux fois par an. La configuration particulière de la Côte bénino-togolaise, plus en retrait dans le Continent, détermine à son niveau la divergence des vents humides du Sud-Ouest, cause prépondérante de la subsidence qui confère au climat de cette région un caractère plus sec, comparativement à l'ensemble du Golfe.

Le régime climatique résultant est caractérisé par une pluviométrie annuelle bimodale inférieure à 1500 mm, et des données d'évapotranspiration potentielle relativement stables toute l'année, en raison de la stabilité des conditions énergétiques (Fig.2).

Le rayonnement global moyen reçu au sol reste compris entre 400 et 500 Cal.cm⁻¹.jour⁻¹, la tension moyenne de vapeur d'eau de l'air entre 26 et 32 millibars et la température moyenne annuelle entre 26 et 27°C, l'amplitude thermique ne dépassant guère 5°C quelle que soit la station considérée.

La pluviométrie demeure le paramètre climatique le plus variable de la zone. L'analyse fréquentielle des événements climatiques a permis d'établir les caractéristiques des deux saisons de pluies (FRANQUIN, 1972 ; VAN DIEPEN et AZONTONDE, 1979 ; F AO, 1984), la connaissance de la date du début des pluies utiles étant particulièrement importante pour les activités agricoles (Tableau 1). Le caractère sec de la zone côtière du Bénin et du Togo est d'autant plus affirmé que la longitude est faible. C'est dans le secteur Ouest que les saisons des pluies sont les plus tardives et les plus courtes.

L'état moyen du régime climatique ainsi établi recouvre une grande variabilité inter annuelle, notamment en ce qui concerne les précipitations atmosphériques.

En effet, l'examen des séries de données pluviométriques les plus longues disponibles dans la région côtière bénino-togolaise fait apparaître
Tableau 1 - Caractéristiques des saisons de pluies de la zone côtière bénino-togolaise.

<table>
<thead>
<tr>
<th>SAISONS</th>
<th>DATE DEBUT</th>
<th>DURÉE PÉRIODE HUMIDE ($P &gt; ETP$)</th>
<th>DURÉE TOTALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ère</td>
<td>11-18 MARS</td>
<td>61-91 jours</td>
<td>128-148 jours</td>
</tr>
<tr>
<td>2ème</td>
<td>1-30 SEPTEMBRE</td>
<td>15-26 jours</td>
<td>33-71 jours</td>
</tr>
</tbody>
</table>
qu'entre 1921 et 1987 toutes les stations ont été affectées par des variations pluviométriques de même sens et de fortes amplitudes (Fig. 3). La hauteur d'eau annuelle la plus élevée a été observée dans les stations en 1968, et la plus faible en 1977, avec entre ces deux valeurs extrêmes un rapport voisin de quatre (4). La représentation de la moyenne mobile sur sept (7) années des données annuelles fait ressortir le synchronisme des tendances du régime pluviométrique et l'alternance des tendances sèches et humides dont la période d'occurrence est de l'ordre de 15 ans.

Le caractère sec ou humide d'une décennie semble s'affirmer de manière équilibrée sur les deux saisons de pluies et sur toutes les phases d'une même saison (Fig. 4). La conséquence pratique que tirent les populations locales de cette observation est d'orienter leurs activités saisonnières sur la base des seules données de la première saison des pluies.

2 - MODE D'ADAPTATION DES BIOCOENOSES AUX OSCILLATIONS CLIMATIQUES

La zone climatique côtière du Bénin et du Togo domine le bassin sédimentaire côtier que l'on peut diviser en deux domaines distincts caractérisés chacun par une biocoenose spécifique: la plaine côtière à mangrove et le plateau côtier à savane arbustive.

2.1 - La Mangrove côtière

La plaine côtière bénino-togolaise est une étroite bande littorale de largeur croissante d'Ouest en Est qui atteint une largeur maximale de 10 km au Sud de Porto-Novo. D'altitude partout inférieure à 10 m, elle est constituée de cordons littoraux séparés par des lacs, des bas-fonds marécageux et une lagune côtière large de 200 à 1500 m et qui relie la banlieue de Coton à la lagune d'Aného au Togo sur une longueur de plus de 60 km. A l'Est de la plaine, la lagune de Porto-Novo est reliée par un chenal au lac Nokoué à Cotonou, si bien que toute la plaine côtière est parcourue de plans d'eau alimentés par l'Océan Atlantique et/ou les fleuves tributaires de l'Océan.

Le domaine de la Mangrove est celui de la Lagune Côtière. La biologie de cette mangrove n'est pas fondamentalement différente de celle de mangroves tropicales connues (ULISS, 1967; PARADIS, 1976, 1979; GAILLARD et al., 1982; p. 0, 1985). Elle est même relativement pauvre en espèces, les taxons
caractéristiques représentées dans la Mangrove bénino-togolaise étant seulement les Rhizophoracées, les Verbenacées, les Combretacées, les Aizoacées, les Amaranthacées, les Adiantacées et les Poacées (BAGLO et al., 1988). La particularité de cette mangrove réside dans ce que, ouverte sur la mer par la seule embouchure des fleuves Mono et Couffo, elle ne se trouve pas directement influencée par les mouvements de la marée. La Lagune Côtière est alimentée par l'eau douce des fleuves pendant la saison des pluies continentale (Mai à Octobre) et par l'eau de mer au cours de la saison sèche continentale (Novembre à Avril) qui recouvre la grande saison sèche côtière (Décembre à Mars). Cette configuration particulière de période sèche annuelle est favorable à l'évaporation physique de l'eau de la Mangrove, à l'accroissement de sa salinité (fig.5), à la remontée capillaire d'eau salée sur les sites d'où l'eau s'est retirée, à la cristallisation du sel à la surface du sol et en définitive, à des activités de production de sel de cuisine par les populations locales.

Au Bénin et au Togo, les communautés locales désignent le sel de cuisine par l'expression "terre de XULÁ", du nom du terroir lagunaire bénino-togolais à mangrove, où les traditions orales ont établi que, dans un passé lointain, le sol était constitué de blocs de sel que les populations allaient ramasser pour leur usage alimentaire. Aujourd'hui, on n'observe, sur la région aucun point d'accumulation de sel, mais les habitants s'adonnent en saison sèche à d'intenses activités de production de sel consistant à provoquer la remontée capillaire de l'eau de la nappe salée, à racler les efflorescences de sel déposées après l'évaporation de l'eau, à lessiver le mélange de sel et de terre récoltée à l'eau salée concentrée de la Lagune et à faire cristalliser le sel par chauffage de la saumure obtenue. La masse de sel ainsi produite chaque année est supérieure à 2 000 tonnes (BAGLO et al., 1988).

Ce témoignage vivant suggère l'hypothèse de l'existence, dans un passé lointain, d'une séance climatique particulièrement humide et de longue durée ayant pu entraîner l'inondation de la région par de l'eau saumâtre et la constitution d'une nappe salée; une séance suivante plus sèche, aurait provoqué l'évaporation de l'eau et l'accumulation de sel dans le paysage. Durant cette dernière séance qui se poursuivrait encore aujourd'hui, c'est l'exploitation des dépôts de sel par les populations qui serait à l'origine de l'épuisement desdits dépôts et aurait contraint les
populations à développer la technique actuelle d'extraction de sel à partir des réserves du sol.

Malgré les études entreprises dans la Mangrove depuis les années 1950, on ne dispose d'aucun élément solide susceptible de vérifier cette hypothèse, les recherches n'ayant pas été orientées dans ce sens. Il reste souhaitable que soient développées des thèmes de recherche visant une meilleure compréhension de l'histoire de la Mangrove côtière bénino-togolaise.

La production de sel est la principale activité économique des riverains de la Mangrove. Tous les moyens de production sont tirés de la Mangrove, notamment les matériaux de chaufâe constitutés de branches, de troncs et de racines de palétuviers (Rhizophora racemosa et Avicennia africana). L'exploitation du sol de la Mangrove par raclages successifs en saison sèche a donné lieu à la recolonisation de l'espace par trois groupements herbacés qui se succèdent dans le temps :

- le groupement à Sesuvium portulacastrum L. dans les sites les plus salés ;
- le groupement à Philoxerus vermicularis R. Dr. sur les surfaces de salinité moyenne ;
- le groupement à Paspalum vaginatum Sw. dans les sites les moins salés.

Le premier groupement est celui qui domine en année sèche et qui a tendance à prendre de l'extension au cours de ces dernières années. De même, on assiste à l'appauvrissement de la Lagune en poissons, probablement à cause des seuils élevés de salinité atteints en fin de saison sèche ces dernières années.

Tous ces indices portent à penser que les faits climatiques ont influencé et continuent d'influencer directement et indirectement l'équilibre de la Mangrove côtière bénino-togolaise. Ces indices s'accordent avec la tendance à l'assèchement climatique actuellement enregistrée dans toute la zone côtière. Abattage massif de palétuviers en année humide pour les besoins de chaufâe de la saumure peu concentrée, et raclage de grandes superficies de sol en année sèche pour les besoins de grosse production de sel, telles sont les actions majeures de l'homme dans l'écosystème Mangrove et qui
consacrer à coup sur la dégradation et la destruction de ce milieu particulier si la recherche scientifique ne vient pas apporter les solutions pertinentes qu'appelle la sauvegarde du juste équilibre entre milieu physique et milieu biologique.

2.2 - La Savane arbustive

La Savane arbustive occupe le plateau de sols ferrallitiques plus ou moins dégradés, très épais, développés sur le Continental Terminal faisant suite aux cordons littoraux. Ce plateau de largeur croissante d'Ouest en Est atteint la largeur maximale de 100 km au Nord de Porto-Novo pour une altitude maximale de 100 m.

La Savane arbustive côtière est la zone la plus peuplée du Bénin et du Togo avec une densité de population supérieure à 150 habitants/km² pour une densité moyenne de 38 habitants/km² sur le territoire des deux États. C'est dire que l'action de l'homme est prépondérante dans l'écosystème.

La végétation naturelle a pratiquement disparu, sauf dans quelques îlots forestiers localisés dans les sites sacrés, protégés par les populations, et dans la dépression médiane qui traverse le plateau sédimentaire d'Ouest en Est, et où quelques taxons caractéristiques donnent des indications sur le couvert végétal original. La végétation de référence était dominée par les Moracees et les Sterculiacées à l'Est du plateau, les Bombacacées au Centre et les Arécacées de l'Est à l'Ouest, notamment le palmier à huile (taes guineensis Jacq.).

La présence de représentants hygrophytes de ces taxons dans les îlots forestiers témoigne d'une séquence climatique humide ancienne sur le plateau et du rôle de l'homme dans l'accélération du processus de sauvage. Une étude approfondie s'impose pour préciser le contour des grands cycles d'évolution de l'écosystème et leur rapport avec les grandes oscillations climatiques.

Aujourd'hui on assiste à l'élimination progressives des hygrophytes stricts dans les îlots forestiers; même le palmier à huile se trouve en difficulté dans les peuplements naturels ou cultivés communs sur le plateau
Figure 4 - Pluviométrie moyenne mensuelle à Cotonou au cours de la décennie sèche 1937-1946 et de la décennie humide 1954-1963.

Figure 5 - Variations de la salinité de la Lagune Côtière bénino-togolaise au niveau de la Mangrove de Djègbadjì au cours de l'année.
Fig. 3 - Données annuelles (A) et moyenne mobile sur 7 ans (B) de la pluviométrie à Cotonou, Porto-Novo, Ouidah et Grand-Popo durant la période 1921 - 1987.
La savane arbustive côtière du Bénin et du Togo est formée de mosaïques de cultures et de jachères à *Dalium guineense* Willd., *Lophira lanceola* et *Psidium guayava* L. sur une épaisse couverture herbacée dominée par *Panicum maximum* Jacq. et *Imperata cylindrica* (L.) P. Beauv.

Les cultures pérennes sont essentiellement les plantations de palmier à huile qui font suite aux escotières des cordons littoraux. La mort de palmiers par déshydratation et dépérissement du bourgeois terminal, caractéristique du stress hydrique, est observée dans tous les peuplements non irrigués depuis une quinzaine d'années. La réaction immédiate des institutions nationales de recherche a été d'initier des Programmes d'études sur la résistance de l'espèce à la sécheresse, aux fins de sélectionner des lignées capables de s'adapter à la séquence climatique sèche observée dans la région. Aucun résultat tangible n'est encore obtenu mais les perspectives sont prometteuses. Cependant, il est évident que tant qu'on n'aura pas une bonne connaissance des cycles climatiques en cause, aussi bien dans leurs périodes que dans leurs amplitudes, notamment en ce qui concerne les seuils maximum de déficit hydrique et leur durée de persistance dans la région, les solutions les mieux élaborées seront rapidement remises en cause.

En matière de cultures annuelles, les plus grandes superficies agricoles sont consacrées au maïs (*Zea mays* L.) et au manioc (*Manihot esculenta* Crantz). Si la plasticité écologique du manioc lui permet d'assurer aux agriculteurs un niveau de rendement acceptable quelle que soit les conditions pluviométriques de l'année, par contre le maïs n'offre aucune garantie de production si un important déficit hydrique intervient durant les stades phénologiques de formation des fleurs femelles et de floraison mâle. C'est pourquoi les agriculteurs du plateau côtier subordonnent systématiquement la taille des superficies à ébaler en maïs à l'importance des pluies enregistrées durant la première phase de la saison des pluies, et qui donnent généralement une bonne indication sur la pluviométrie annuelle attendue (Fig.4). Cependant, en raison de la présence des saisons marginales débutant par de grosses pluies suivies de longues périodes sèches, le parallélisme entre l'évolution des données annuelles de superficie de maïs et de pluviométrie n'est pas toujours parfait (Fig.5). Cette stratégie paysanne dont l'efficacité à stabiliser le rendement unitaire des parcelles ne souffre d'aucun doute entraîne néanmoins une variation trop grande des surfaces cultivées annuellement, sans commune mesure avec l'ampleur réelle des com-
Fig. 6 - Evolution de la superficie des cultures de Maïs et de la pluviométrie au cours de la période 1969-1986 dans le bassin sédimentaire côtier du Bénin.
traitées climatiques. Une telle stratégie a besoin, sans aucun doute, de s'appuyer sur des bases analytiques solides qui restent à établir. Dans ce domaine aussi, la recherche agronomique compte des études ayant débouché sur des acquis tangibles. Mais les variétés de maïs tolérantes à la sécheresse ou à cycle court proposées aux paysans par les institutions nationales de recherche et les institutions internationales telles que le SAFURAD et l'Institut International d'Agriculture Tropicale sont généralement mal acceptées pour des raisons liées à leurs qualités organoleptiques non conformes au goût des populations.

Une deuxième stratégie mise en œuvre par les agriculteurs pour faire face à l'assèchement climatique observé dans la région est de développer la pratique de l'association des cultures. Dans le secteur Ouest de la zone, où la pluviosité est la plus faible, il n'est pas rare d'observer plus de cinq (5) espèces végétales cultivées dans une même parcelle (maïs, manioc, piment, gombo, tomate, arachide, niébé, cotonnier, ...). Si elle est convenablement conduite, cette stratégie est compatible avec les exigences de l'agriculture de subsistance, mais elle ne peut conduire à l'économie de marché, au développement agricole véritable.

Au total, le problème de l'adaptation des activités agricoles du plateau sédimentaire côtier du Bénin et du Togo aux changements climatiques de la région demeure entier, faute d'une bonne maîtrise des analyses scientifiques devant y conduire.

CONCLUSION

Le domaine côtier bénino-togolais qui appartient au secteur le moins arrosé du Golfe de Guinée est le siège de fluctuations climatiques déconnaissantes mises en évidence par les séries d'enregistrements météorologiques continus élaborées à partir de l'année 1921; il est également le siège d'oscillations climatiques d'amplitude et de période plus grandes, soutenues par des témoignages vivants, sociologiques et biologiques, et dont les contours restent à délimiter.

Ces changements climatiques ont profondément marqué la Mangrove côtière et la Savane arbustive, directement et avec la complicité de l'homme
car, dans cette région à forte densité de population, l'homme est partout présent et fait partie intégrante de l'écosystème. Les cycles d'assèchement actuellement en cours d'évolution dans la zone ont amené les populations locales à mettre en œuvre des stratégies d'extraction de sel de cuisine dans la Mangrove et des stratégies de production agricole vivrière dans la Savane, stratégies dont les fondements sont peu solides, faute de soubassement scientifique dont les armatures débordent du cadre strictement local.

C'est pourquoi il est souhaitable que la coopération scientifique internationale joue pleinement son rôle dans le secteur supra national de la climatologie, aux fins de doter les communautés les plus menacées par la sécheresse des outils nécessaires à leur propre autodéfense.

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Tableau 1 - Caractéristiques des saisons de pluies de la zone côtière bénino-togolaise.

<table>
<thead>
<tr>
<th>Saison</th>
<th>Date Début</th>
<th>Durée Période Humide (P &gt; ETP)</th>
<th>Durée Totale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ère</td>
<td>11-18 Mars</td>
<td>61-91 jours</td>
<td>128-148 jours</td>
</tr>
<tr>
<td>2ème</td>
<td>1-30 Septembre</td>
<td>15-26 jours</td>
<td>33-71 jours</td>
</tr>
</tbody>
</table>
CLIMATIC CHANGE AND HUMAN BEHAVIOUR

(by Paul MCHOJI NKWI)

After having attended at least four conferences or workshops in the past 18 months that places the environment at the centre of discussions, I have come to the conclusion that man is seeing looming in the horizon the destruction of the human species. Whether we talk about the depletion of the ozone layer or about the preservation of the biodiversity in our universe or we raise the issue of food security, we do so with the explicit conviction that man must survive; the PAN-EARTH group's objectives and concerns are genuine and falls within this constant struggle of man to survive. The biblical NOAH's Ark phenomenon recounts again the salvation of biodiversity thousands of years ago. Whether that took place as recounted or not, is besides the points. Man's concern about his survival as a species is as old as history.
Today, psychologically those who own nuclear capability are fully aware of the consequences of any form of nuclear drop-out and they are afraid or awase of the possible destruction of man, his culture, civilisation and technological achievements. Man's behaviour in the face of such instruments of death is one of caution, fear, and preparedness. If presence of gases in the atmosphere, has led man to realise the damage already done to the atmosphere around our globe, man must act with caution to limit the further emission of all kinds of gases that may lead to man's total destruction. It is the common concern of all: black, white, green, yellow: you name it. Collective conscious human behaviour towards the deterioration of our environment is imperative.

In cultural dynamics one theory holds that radical/major changes in patterns of human behaviour can only occur in situations of revolutions, disaster (natural or artificial). In most circumstances, societal changes take the form of cultural drift; that is the societal behaviour changes gradually and in an unperceptible way. Drastic climatic changes falls within the category of natural disaster and will certainly have serious consequences on human behaviour, human habitat or settlement patterns.

Historically: climatic changes have been responsible for mass population movements, changes in agricultural practices and political re-organisation. These were mass migration of ethnic groups from hostile ecological niches to more friendly
environments. These movements have always been accompanied by a radical review of cultural patterns and societal norms and morals.

Thousands of years ago African groups living in present Sahara regions moved south as climatic conditions became intolerable. One group on its journey south left traces of its culture and civilisation in rock paintings either in caves or on open-air rocks. Man used therefore natural shelters before inventing more adequate settlement patterns.

Glacial period destroyed partially biodiversity. The widespread of the Peuls in West Africa has often been attributed to climatic as well as political circumstances.

The desertification phenomenon of the 1970s is still vivid in our minds. Many groups, lost cattle, crops and their families. It has taken many groups to re-adapt to a new life style without cattle, or without ritual shrines abandoned in search of less hostile ecological niches.

Can we work out a model based on human-behaviour—or is it possible to make a social forecast if nuclear winter simulation is taken into account? Let us look at some of the basic variables that are essential in this equation: population growth, agricultural potentials, political and economic systems.
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Can we work out a model based on human-behaviour—or—is it possible to make a social forecast if nuclear winter simulation is taken into account ? : let us look at some of the basic variables that are essential in this equation : Population growth, agricultural potentials, political—and economic systems.
The Population of Africa is growing at an average rate of 3 - 4 per cent and represent the highest rate in the world.

Twenty years ago the population was about 270 million now it is about 400 million; it is expected that it will triple by 2025 if nothing is done to control it.

If population continues at the rate at which it is growing, we are bound to have thousands of people competing for the scarce resources (fertile land, encroachment on the reserve etc...).

The most states have not elaborated effective population policies: they are still basically pro-natalists: people are virtually paid to have babies. Although birth control or population control has been adopted by many nations, the strategies are ineffective; and change in mentality has not yet occur to produce any significant effect on population growth.

Rural exodus is a phenomenon of enormous proportions in most African countries. The cities are over-crowded with people looking for jobs, none can be found. Social unrest is bound to occur if adequate solutions are not found: crime is on the rise (arm robbery); there is an increase in the number of female headed households; prostitution is on the rise.
Food supply is inadequate and most African countries cannot boast of being able to feed its population. The absence of food banks cannot guaranteed food security. That explains why most African governments have made agriculture their priority number one. The fall of prices of primary products (cocoa, coffee etc) in the world market have thrown African nations into economies desarray and into serious financial problems. In some countries civil servants have not been paid their salaries for several months. Imagine how people will behave if climatic changes would further aggravate an already delicate situation.

How would humans behave politically, agriculturally, religiously and economically if climatic conditions do change drastically?

Looking at African food patterns and policies, it is apparent from projections that in the case of nuclear winter, Africa will be most affected. From the agricultural point of view food might be available only for two months and the effects will be uneven throughout Africa. If climatic conditions will lead to the absence of rain and sunlight people in the semi-arid regions will be most affected or exposed to severe famine because there will be natural food availability.

People in the forest may survive a little longer by living on wild fruits, tubers or leaves. A study of this natural food potential is crucial/critical. Nomads/pastoralists will loose...
all their cattle and their way of life will be totally reviewed
in the light of new opportunities if there will be any.

In the event of drastic changes the political, economic and
religious systems will collapse if solutions cannot be found
either for the hierarchical/centralised, segmentary or modern
systems. Economic systems will be destroyed. Agricultural
economic based system will cease to exist if the agricultural
basis is destroyed. Other social factors will be modified and
cultures and civilisations will disappear. Let me use as an
example of a recent gas explosion in Cameroon. In 1986 1700
people were killed the survivors abandoned their farms, sacred
shrines, shops and since then no survivors has ever returned to
their original village. Their way of life and settlement has
changed drastically.

STRATEGIES FOR THE FUTURE.

1. Sensitisation of our people to the dangers of some of
the agricultural practices - deforestation, bush fires;

2. Associate the people in the elaboration of policies that
seek to improve our environment;

3. Associate them in the managements of the scarce
resources;

4. Systematic introduction of environmental education into
our school curricula.
introduction

A lot has been written on the changing climate of sub-Saharan Africa in recent years. The changes are most often defined in the context of droughts or rate of desertification. The concept of destruction of biological potential and especially its rate of advance which the desertification invokes have generated much controversy. But the point that cannot be disputed is the statistics on the frequency of famines and the huge number of accompanying deaths through starvation. Indeed, because of the more graphic nature of the disasters associated with the climatic changes in the sub-Saharan Africa and the difficulty in measuring the cause, most publications on the situation have dealt only with the social and economic consequences of the changes and the responses thereafter. Mortimore (1989) gives a most up-to-date listing of available literature on drought and desertification in this area.

This paper will, primarily, look at the agriculturist's perspective of the changing climate. It will assess what information exist for rational appraisal of climatic change and review the farming systems in Nigeria's Northern Guinea and Sudan savannas. The objective will be to highlight areas of weakness or areas that need urgent attention if the agricultural development plans of Nigeria and indeed the West African region is not to remain permanently frustrated.

data base

The Institute for Agricultural Research, Samaru (IAR) which had until recent been the only establishment responsible for agricultural research in the Nigerian
savanna maintains a data pool of available weather records in the area. The climatic assessment is based on analyses of the IAR data which covers a total of 170 stations. A critical assessment of the data shows that the density of the monitoring points is low (about 1 in 3,800 km$^2$) but even more desperate if looked at from the number of comprehensively equipped weather stations (approximately 1 in 16,000 km$^2$). Kano (Lat. 12°03′N and Long. 08°32′E) which has the longest recording began operation in 1905. About 52 percent of the Weather Stations have been recording for just 20 years or less. Poor supervision and inadequate maintenance of some of the stations caused discontinuities lasting from a few days to some years in 25 percent of the locations. The following assessments are based on analyses of data from the IAR records.

Rainfall

The Nigerian savanna received heavy rainfall in the 1950s from which time rainfall has gradually declined to the present. Figure 1 gives a decade by decade illustration of the decline at Kano and Samaru while Figure 2 shows the trend of both annual rainfall receipt and date of start of the rainy season. Ojo and Oyebade (1987) published the mean drought index for the Sahel; Sudan, Guinea and Forest vegetation zones of Nigeria using data from 45 weather stations. Their results for the Guinea, Sudan and Sahel savannas follow the pattern in Figure 2. Thus, while the pattern of decline is not consistent, the overall tendency in the last 30 years is for lower rainfall and later start of rains in Nigeria's Guinea and Sudan savannas.

Yeyock and Owonubi (1986) also showed the inter-relationship of potential evapotranspiration (ET) to rainfall from 1958 to 1983. The situation is that of a shrinking length of rainy season and an increasing rate of ET. Their data for the first three years in the 1980s showed that the beginning of the humid season (when ET is higher than precipitation) has been delayed by about 12 and 30 days compared to 1971-80 and 1961-70, respectively. The end of the humid season was conversely hastened by 3 and 10 days relative to 1971-80 and
Fig 1: Progressive evolution in total annual rainfall at Kano and Samaru (Nigeria) for the period 1927-88
Fig 2: Pattern of annual rainfall and date of start of rainy season at Samaru: 1928-88
1961-70. For specific droughty years, the contrast to the normal rainfall pattern can be extremely adverse (see figure 3, re-drawn from Mortimore, 1989). According to Yayock, Rossel and Harkness (1976), a reduction in the days to normal harvest of a 120-day groundnut crop in the fragile Sudan savanna area of Nigeria can lead to as much as 35 percent decrease in yield (Figure 4).

**Solar Radiation**

Less known but equally drastic changes may have occurred in solar radiation receipt and distribution within the last 30 years in the sub-Saharan Africa as exemplified by Samaru sunshine hour (determined by Campbell - Stokes sunshine recorder) split into decades in Figure 5. It is important to note that while the mean sunshine hour per decade has decreased from January to April and October through December, the reverse has taken place from July to September. The increasing trend of sunshine during the period of peak rainfall suggests a decrease in cloudiness at this time and may have accounted for observed reduction in annual rainfall.

To the contrary, the decreasing sunshine during the dry seasons of recent is a reflection of more atmospheric interception and/or reflection of solar radiation which, in the absence of clouds, appears to have been caused by higher dust content in the NE wind prevalent at this time. This has necessitated a closer monitoring of the effects of the harmattan as detailed below.

**The Harmattan**

Several reports of occasional over-pass of dust-laden NE trade winds arising from the Sahara towards the Atlantic coast of West Africa, and locally referred to as the harmattan have been published (see Grigoriev and Lipatov, 1974; Idso, 1976). In fact, the IAR made initial analysis of the dust in the early seventies (Bromfield, 1974). But the harmattan has today become a household name during the dry season across West Africa as it has assumed a major economic factor to aviation, communication and probably, agriculture (Owonubi, Olarewaju and Ajayi, 1982). The rate and distribution of harmattan dust settling at Samaru during
Figure 3: Re-evaluation lines for the start and end of the rains in 1973 and in an average year. (c) Length of the rainy season and the southwestern part of the northern hill of millet and groundnut production in 1973 (after Kowal and Ackroyd, 1977; Kowal and Kasmin, 1973, 1978: 109-110).
Fig 4: Relationship between the harvest yielding percentage relative to reduction in days to normal harvest
Fig 5: Trend of solar radiation at Samura between 1954 and 1988
the dry seasons between 1984 and 1988 have been plotted in figure 6.

Prior to 1970, even though dust over-passes frequently reduced incoming solar radiation, it did not occur at a scale that caused zero sunshine records at Samaru. However, beginning from 1970, the savanna zones of Nigeria have measured zero sunshine hour often and within broader time limits of the dry season (Table 1). In assessing the trend of occurrence of these intense dust-storms, as presented in Table 1, it is pertinent to note that the 1985-89 period is for four seasons as against the 5-year totals listed from 1970 through 1985. Preliminary investigations (Owonubi, Olarewaju and Ajayi, 1982) have indicated that the settling dust may reduce the yield of dry-season tomatoes. The same may be true of perennial trees or vegetation.

Table 1. Number of days with dust-induced zero sunshine records between 1970 and 1989 at Samaru.

<table>
<thead>
<tr>
<th>Time</th>
<th>Number of Days</th>
<th>Period of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-75</td>
<td>8</td>
<td>Dec 11 - Mar 10</td>
</tr>
<tr>
<td>1975-80</td>
<td>14</td>
<td>Nov 21 - Mar 20</td>
</tr>
<tr>
<td>1980-85</td>
<td>50</td>
<td>Oct 1 - Mar 10</td>
</tr>
<tr>
<td>1985-89</td>
<td>47</td>
<td>Nov 1 - Apr 30</td>
</tr>
</tbody>
</table>

Ecological Boundaries

One of the basic assumptions in writing on climatic change in the Northern Guinea and Sudan savannas is that the geographical limits of the ecological zones have been well defined. The major work for delineating the ecological zones of the Nigerian savanna had been done by Keay (1959) and Higgins et al (1960). The works formed the base of the atlas by Kowal and Knabe (1972) which is now about 20 years old. Some of the criteria used for differentiating the ecological zones included annual rainfall amount, length of the rainy season, type
The rate and distribution of harvesting dust settling at January during the dry season of

TIME

DUST SETTLING RATE
and density of vegetation.

The changes in the climate enumerated earlier in this paper would have significant effects on the vegetation. So also is the recent creation of very large dams which, in pooling large volumes of water at a few locations, may have deprived the numerous rivers and streams that criss-cross the Nigerian savanna of substantial water required to balance the original ecological dynamics. Indeed, Barbour et al. (1982) and Yayock and Owonubi (1986) observed a shift in the ecological boundaries in this area. More detailed work (especially including ecologists) is required to up-date the current status and boundaries of the Nigerian vegetation.

**Crop Production**

Because of the higher economic benefits derivable from crops as compared to natural vegetation in this area, routine statistics on crop type and quantity produced per location are more readily available than vegetation type and dynamics.

Results of surveys published by Mortimore (1989) showed that some villages in the Nigerian Sudan savanna had mean yields of early millet, sorghum and groundnuts, respectively, reduced to 12, 4 and 7 percent of normal during the 1973 drought. Another way of assessing crop losses attributable to changing climate is by simultaneously determining possible yield "if the climate were normal. Davies (1987) published yields of groundnut under rainfed and with supplementary irrigation during the droughty 1982-84 years at Kano (Table 2). The increase of irrigated crop yield over rainfed ranged from 66 to 442 percent.

**Table 2. Groundnut: rainfed and supplementary irrigation trials in Kano**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total rain (mm)</th>
<th>Rainfed crop yield (kg/ha)</th>
<th>Supplementary irrigation (mm)</th>
<th>Irrigated crop yield (kg/ha)</th>
<th>% increase over rainfed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>638</td>
<td>1614</td>
<td>160</td>
<td>3107</td>
<td>93</td>
</tr>
<tr>
<td>1983</td>
<td>432</td>
<td>580</td>
<td>110</td>
<td>3145</td>
<td>442</td>
</tr>
<tr>
<td>1984</td>
<td>507</td>
<td>950</td>
<td>115</td>
<td>1580</td>
<td>66</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>1048</td>
<td>2614</td>
<td></td>
<td>150</td>
</tr>
</tbody>
</table>
Cropping Systems

Using the cropping system definitions of Gosden (1978), the results of IAR farming system surveys are summarized in Figure 7. The Millet-Sorghum systems approximates the Nigerian Sahel which we now observe to have cut across the northern fringe of Nigeria including parts of Sokoto, Katsina, Kano in addition to Bornu States. Even though millet is the dominant crop, some cowpea and groundnut are also grown. Cattle production is important and animal draft widespread.

The Sorghum - Millet - Cowpea system is found in the southern parts of Kano, Sokoto and Bornu, and northern Bauchi states. Cattle production is important in this area which also produces cotton, groundnut and maize.

The Sorghum - Millet - Maize system features prominently Kaduna State and the southern part of Bauchi state where cotton, groundnut and yam are also grown. This system along with the Sorghum - Millet - Cowpea system occupy the Northern Guinea and some parts of the Sudan savanna zones. The two sytems have recently been referred to as the Permanent Systems with Sorghum because of the continuous use of the same cropped land for growing a range of crops subsidiary to sorghum.

There are local variations to this general classification. The more important of these variations are the Acha - Dauro Millet system of the cool Jos Plateau; the traditional swamp Rice system of river valleys of the Sokoto, Rima and Jama'are; and the Masakwe Sorghum system of the flooded vertisols around Lake Chad. A conspicuous deviation from Kowal and Knabe (1972) and Barbour, et al. (1982) is the reduced importance of groundnuts, cotton and sorghum in the Sudan and Sahel savannas where adverse climate has increased the risk of growing these crops. Conversely, maize has recently gained more ground in the Guinea savanna largely because of its relatively high yields and easier production compared to either sorghum, cotton groundnut or cowpea.
Fig. 7: Farming systems of Nigeria, Northern Guinea, Sudan and Sahel savannas.
References


DROUGHT IN AFRICA: A SYNTHESIS OF CURRENT SCIENTIFIC KNOWLEDGE

E.O. Oladipo*

ABSTRACT

In this review, the current scientific knowledge about the spatial and temporal characteristics of African droughts and their causal mechanisms are examined. Some drought amelioration measures are also discussed.

In general, droughts in Africa have a rather incoherent time and space scales of occurrence. This will suggest that explanations for drought cannot be sought only in terms of synoptic controls over the continent, but also in terms of sub-synoptic atmospheric processes. Because of the random fluctuations that seem to dominate drought spectra, there is only a very faint ray of hope that drought in Africa can be predicted years in advance by statistical means.

Judging from the haphazard manner in which the 1983 drought was handled in Nigeria, there is an urgent need for African nations to establish drought control plans that are capable of ameliorating its consequences.

Introduction

Information about a normal climate, as given by the mean values, is less useful for planning purposes than knowledge concerning the occurrence and magnitudes of climatic extremes. Atmospheric behaviour fluctuates on various time scales (e.g., a week, a month, a season, a year, etc.) over the entire earth. Knowledge of these various climatic states is now accepted as an important stage in understanding the atmospheric environment and the impact of its variable behaviour on human activities.

Of all the time scales of climatic fluctuations, the short-term (annual to decadal) variability is becoming of increasing importance because of its potential damaging effects. The high degree of rainfall variability that has plagued different parts of Africa, particularly the semi-arid zones, has been of great public concern. A consequence of precipitation variability, which is of special importance to agriculture, is the occurrence of extended periods with much less than normal rainfall, often referred to as drought. The occurrence of widespread droughts with crop failures in some parts of Africa and major floods in others have heightened the concern about the possibility of a major climatic swing into a more variable phase with attendant disruptions. There is great interest in understanding the subtle climatic fluctuations which may be harbingers of larger changes to come (e.g. Odindo, 1977; Oguntoyinbo and Odindo, 1979).

This paper surveys some of the available literature on the climatic aspects of droughts with emphasis on our current scientific knowledge about frequency of occurrence (prehistoric and historical droughts), spatial and temporal characteristics, causal mechanism and amelioration measures. The objective is to synthesize disjointed scientific facts about droughts in Africa into a coherent piece of work.

What is Drought?

There is no universally accepted definition of drought because it is often the result of many complex factors interacting with the environment. Complicating further the problem of definition is that drought is a creeping phenomenon with neither a distinct start nor finish (Whilhite and Glantz, 1985). It is recognizable only after a period of time, and because a drought may be

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interrupted by one or more wet periods, its end is often difficult to recognize.

Drought means different things to different people, depending on their areas of interest or their dependence on the availability of water and the use of it. Good expositions of the problems of drought definition are given in Subrahmanyan (1967), Hounam, et al., (1975), and Matthai (1979). A recent review is given by Dracup et al., (1980), although they failed to offer any other concise definition. There are four commonly used definitions based respectively on meteorological, hydrological, agricultural and economic considerations.

Meteorological definitions of drought are the most prevalent. The commonly used definition is due to Palmer (1965) who described drought as "an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of climatically appropriate moisture supply". Other definitions based only on precipitation include: (i) a period of 21 days or longer with less than 30% of the mean for the time and place, with extreme drought occurring when rainfall fails to reach 10% of normal for 21 days or more (Hounan et al., 1975), (ii) a year having less than 85% of normal precipitation (Thomas, 1962; Nace and Pluhowski, 1965), and (iii) a period of at least 15 consecutive days none of which received as much as 0.25mm (Hounan et al., 1975).

Similar to meteorological drought are the climatological and atmospheric droughts. Climatological drought is defined in terms of precipitation deficiencies, not in specific quantities, but as a ratio to mean or normal values. Atmospheric drought involves not only precipitation but possible temperature, humidity or wind speed and is used to indicate the dryness of the air.

Because meteorological drought fails to take into consideration the amount of water that is needed relative to that available, agriculturalists are usually concerned with soil-moisture deficiencies as they are related to crop yield. Agricultural drought occurs only when the available soil moisture is inadequate to meet evaporative demand by crops (Palmer, 1968).

Hydrological drought, on the other hand, refers to a period of below normal streamflow and depleted reservoir storage during which streamflows are inadequate to supply established uses under a given water management system (Linsely et al., 1975). Whipple (1966) also defined hydrological drought as a period of runoff averaging less than the long-term mean runoff.

The economist sees droughts from an entirely different point of view; that of the areas of human activity affected. From the supply and demand perspectives, drought may be defined as "a rainfall-induced shortage of some economic goods...brought about by inadequate or badly timed rainfall" (Sandford, 1978). This definition implies that the incidence of drought depends not only on rainfall but also on trends in requirements and on factors other than weather, such as water supply management.

The preceding discussion illustrates the diversity of views about what constitutes a drought. Drought is frequently defined according to disciplinary perspective. Although agricultural and meteorological definitions may coincide in the short terms, the two are not necessarily synonymous. A drought may exist in the agricultural sense before it is evident to the meteorologists or hydrologist. On the other hand, an agricultural drought may be ended, at least temporarily, by rainfall that replenishes soil moisture, but which is not heavy enough to contribute to ground-water or stream-flow. An agricultural drought may also exist because of poor temporal distribution of precipitation for the growing season even though the season would be statistically speaking normal or above normal without any meteorological drought in evidence.

Because one is generally more interested in the agricultural consequences of drought, a simple definition of drought may be given as a climatic anomaly involving a deficit of precipitation sufficient to adversely affect crop and animal production and cause severe disruption of the
rural economy. The deficit may arise either because the rainfall fails to reach the level necessary to support the customary agricultural activity or because the rural economy itself develops in such a direction that the "normal" rainfall is no longer sufficient (Palutikof, et al., 1982).

Historical Perspectives of Drought in Africa

Drought as an inevitable part of climate, even in regions with copious rainfall, has been a scourge of mankind since antiquity. Historically speaking, droughts are not uncommon, nor are severe droughts unique to Africa. Our knowledge about the history of drought occurrences in Africa is very sketchy, and the following discussion relies heavily on the works of Nicholson (1976, 1978) and Schove (1977).

Pre-historical Droughts

There are few authentic rainfall records in prehistoric times and much of our knowledge about the occurrences of droughts is based on proxy information such as lake-level variations, pollen data, tree-ring, changes in stream regimes and deposits characteristic of particular types of environment, archives chronicles, travel journals and diaries. In particular the correlation between the height of the Nile flood and rainfall on the Ethiopian highlands has been used to document periods of famine and drought due to failure of rains in Ethiopia. Because the Nile flow has been found to be highly correlated with rains in the Sahel-Sudan zone (Nicholson, 1976), documented evidences of Ethiopian droughts can be expected to have occurred synchronously with other regions of Africa.

Chronology of the low Nile levels as presented in Nicholson (1976) showed that prolonged periods of droughts and famine occurred in the Horn of Africa in about 253—242 B.C., 192—187 B.C., 139—130 B.C. 50—42 B.C., A.D. 12—19, 53—63, 111—124, 151—170 and 254—265. However, the earliest well-documented drought in Africa was in the period 831—849 in Ethiopia (Schove, 1977) and this appeared to have corresponded well with the period of weak Nile floods of 832—842 in Egypt (Nicholson, 1976). Other periods of low levels of the Nile presented in Nicholson (1976, 1978) occurred c.939—953, c.963—968, c.1006—1013 and 1054—1065, but there were no reliable documentary evidences of drought/famine in either Ethiopia or Egypt that can be associated with these weak flows. The next period of drought in Ethiopia was about 1131—1145 (Schove, 1977) and this also corresponded with the weak Nile flows in Egypt in the period 1141—1144 (Nicholson, 1976). Other medieval droughts documented from the Nile flood data included those of c.758—787, c.827—848, c.939—950, c.1009—1017, c.1199—1232, c.1281—1335 and c.1400—1409 (see Nicholson 1976, 1978).

Historical Droughts

Moving forward on the time scale, translations from Arabic chronicles of the western Sudan have provided some information on African droughts. Severe droughts reportedly affected Timbuktu, c.1445—1452, 1538 and c.1587—1588 (see Nicholson, 1978). Similarly, droughts recorded for Ethiopia in the periods 1560—1562 and 1587—1589, while 1621—1622, 1724 and 1784 have also been documented in literature for East Africa (Schove, 1977) as drought periods.

Examination of the Nile flood data and changes in the levels of East African Lakes and Lake Chad (Maley, 1977, 1982) suggested that in the period of 16th through the 18th centuries more humid conditions than those of today prevailed in the Sahel-Sudan region, especially along the southern margin of the Saharan and possibly North Africa as well (Nicholson, 1976). Despite this change to wetter conditions, however, several major droughts were still documented. Three of these episodes which affected nearly the entire Sahel occurred between c.1681—1687, c.1738—1756, and c.1828—1839 with more localized droughts in the early 1700s, the 1770s and
The drought of the 1680s seemed to have covered the entire east-west zones of the Sahel and the Sudan (e.g. Niger, Chad, Benin, Ghana and Senegambia). The long and severe drought that ravaged the entire Sahel-Sudan zone of Central and West Africa in the mid-18th century (c. 1730s—1750s) reportedly (Nicholson, 1978) killed half of the population of Timbuktu and other parts of the Niger bend, and caused famine in Senegambia, Mauritania, Mali, Burkina Faso, Benin, Nigeria and Chad.

More humid conditions may have returned after the mid-18th century until the last decade of the century when a severe drought plagued Chad, Bornu and the Kano area of Nigeria, forcing the evacuation of Agadez (Lovejoy and Baier, 1975). The drought of the 1790s culminated in a severe drought 1828—1839, and this appeared to have been a climax dry period which affected much of tropical Africa and the Sahara from early 1820s to the 1850s or 1860s. The most badly affected area during this dry period was Chad with 12 years of famine and drought reported around Lake Chad (Nicholson, 1976). Other regions of drought include parts of Zambia, Zimbabwe, Angola, Mozambique, Senegal, parts of Ethiopia, Bornu, Maurtania, Mali, South Africa, Algeria and eastern Africa from Ethiopia to Tanzania.

The droughts of 1820s to 1860s appeared to be more widespread and continental in nature than the earlier documented ones (Nicholson, 1976, 1978). Although the documentary and oral evidences relating to the African climatic conditions presented in Nicholson (1976, 1978) and Schove (1977) have helped in the reconstruction of pre-historical and historical droughts in Africa, it is pertinent to point out that such documentary data require considerable effort in order to establish their reliability. Consequently, the drought spectra enumerated in the preceding discussion should be accepted with caution because the interpretation of documentary data is often difficult and debatable.

Droughts in the Instrumental Period

The establishment of many meteorological stations in Africa in the late 19th century provided a climatic record for more adequate description of the intensity and real coverage of drought in the region. Good summaries of the recent droughts in Africa are provided in the works of Lamb (1982, 1983, 1985), Motha et al. (1980), and Nicholson (1979, 1980, 1983). Results presented in these works showed that the sub-Saharan regions suffered tremendous drought in the 1910s, 1940s, 1968—1973 and 1982-1983, with a wetter episode in the 1950s. For areas north and south of the Kalahari and Namib, the 1950s were generally wet, and major droughts occurred in the 1910s and early 1960s. The early 1920s were unique in that they were years of nearly continental droughts with widespread droughts in northern Africa, East Africa and the northern margin of the Kalahari. A trend towards more arid conditions in the late 1970s was evident in many parts of Africa and this culminated in the severe drought that plagued East Africa, Mozambique, Zimbabwe, Zambia and southern Africa for about 4—5 years in the early 1980s.

In general, therefore, large-scale droughts had plagued many parts of Africa in the early 20th century, 1940s and 1969—1973. Although the rains finally returned to normal during 1974—1975 with the exception of a few countries like Togo and Benin, the drought of late 1960s persisted from 1976 to the early 1980s in many areas. In 1981 and 1982 drought extended into East Africa, especially Ethiopia and Somalia, causing enormous economic stress. By late 1982, about 1.2 million inhabitants of Tigre Province in Ethiopia were severely threatened, while in 1983 the Sahel region was badly hit (WMO, 1983). Whether the recent (1988) heavy rains and floods in parts of Ethiopia, Sudan and northern parts of Nigeria are indications of a return to a more humid condition in Africa is too early to predict. It may just be a question of a prolonged drought curing itself tumultuously by giving way to torrential rains for a season or two.
Drought Mechanisms

The preceding section shows that in Africa, droughts have occurred throughout the available historical record and, consequently, one expects it to recur in the future. In spite of this fact, however, it has been very difficult to present a complete explanation for drought occurrence because of the interwoven factors governing precipitation in Africa. Hence, though drought is one of the most intensely studied meteorological phenomena, a satisfactory theoretical explanation of its causes is still lacking. This is not surprising because a good theory will have to account for most of the conspicuous features of drought, such as the persistence of certain atmospheric circulation patterns, the preferences for certain localities, and strong seasonal or annual dependence. In general, a review of factors responsible for lack of rainfall provides a broad framework for understanding the causes of meteorological drought. These factors (see Hare, 1983 for details) include: absence of available moisture in the atmosphere; large-scale subsidence; divergent air flow in the lower troposphere; atmospheric stability; and an absence of rain-bearing systems. Because all these factors are linked to the general circulation, drought, therefore, can be understood as an anomaly in the prevailing regional circulation which reduces the size, intensity or frequency of rain-bearing disturbances.

Some of the major atmospheric features which were observed during the recent drought episodes in Africa have been discussed by Krueger and Winston (1975), Kidson (1977), Kraus (1977), Kamatsumi and Krishnamurti (1978) and Minja (1982). Krueger and Winston (1975) observed a highly anomalous tropical circulation during the northern summer of 1972 and its antecedents. Over Western Arabian Sea and Africa between the equator and 20°N, easterlies were stronger than normal during 1972. It was noted that the anomalous easterlies at 700 mb might have inhibited onshore flow of moisture from the Atlantic region and spread the dry Sahara air over most of the Sahel region.

Kraus (1977) noted that during major drought years in the tropics, tropical convective rainfall systems failed to penetrate into those marginal regions (e.g. Sudan-Sahel) that normally get most of their rainfall during a relatively short summer precipitation season. This means that dryness of a year can be related to abnormally low latitude of the intertropical convergence zone (ITCZ) or intertropical discontinuity (ITD) which is the surface boundary zone between the south-west monsoon and the harmattan winds over West Africa that determines seasonal rainfall variation in the sub-tropics. Reduced northward excursion of the ITD during drought years was explained by Kraus (1977) in terms of reduced cross-equatorial flow of energy toward the southern hemisphere. In particular, it was noted that during the 1972 drought in the Sahel, summer temperatures at 700 mb and 500 mb in the tropics were below normal but above normal in the winter hemisphere, especially around the antarctic, thereby producing a relatively weak temperature gradient. This also means that the mean meridional slope of the 500 mb surface from the tropics to the Antarctica was considerably reduced. Kraus (1977) then hypothesised that a relatively weak meridional temperature gradient and an abnormally flat slope of the 500 mb surface will result in a decreased baroclinity and a reduced generation of extratropical perturbation. This leads in turn to a reduced demand for heat export from the tropics and therefore weak direct tropical circulations. These weak circulations will result in a reduced northward excursion of the ITD and therefore less than normal rainfall in the monsoonal marginal areas. Kraus' (1977) hypothesis is, however, not compatible with the view that polar warming induces increased meridional heat flux (e.g. van Loon and Williams, 1976).

Kidson (1977) observed that the dry conditions during 1972—1973 over the Sahel were associated with the virtual disappearance of the 850 mb trough and the presence of a weak easterly jet at 200 mb, implying a reduction of the meridional circulation. In a similar manner,
Kanamitsu and Krishnamurti (1978) concluded that rainfall deficit over West Africa Sahel in 1972 was due to a weak zonal easterly current. Minja (1982) noted that apart from pockets of confluent zones at 800 mb and 700 mb levels, the Sahel-Sudan zone, East, West and Central Africa were under anomalous diffuent flows during the rainy months of 1972. Confluent transient flow was observed only over the wet regions.

Other empirically derived teleconnections between sea surface temperature warming in the equatorial East Pacific (El Nino) and the tendency for above normal surface pressure in the South Pacific Ocean to be associated with below normal pressure in the equatorial Indian Ocean (Southern Oscillation) and droughts or anomalous rainfall conditions in Africa have also been cited (e.g. Adedokun, 1978; Bhalme et al., 1983; Glantz, 1984; Nicholson and Entekhabi, 1986).

Thus far it has been helpful to list some of the salient views about drought as an atmospheric phenomenon. Such relationships as discussed above should not be mistaken for causes of drought. To establish cause and effects necessitates the separation of the internal and external forcing factors of the climate system. For example, as Kraus (1977) observed, it is very difficult to determine whether a weak meridional temperature gradient of the drought years is caused by a high energy level of the heat transporting eddies or whether, in opposition, the eddy energy level is relatively low because of the decreased forcing. It is also noted that although several major El Ninos have coincided with dry periods in the Sahel (e.g. 1972, 1982), other El Nino events (e.g. 1957) have occurred when rainfall in the region was above normal. These teleconnections will only give us an indication of the magnitude of air-sea interactions, but whether the ocean's role is that of an initiator, collaborator or recipient is still not clear.

In general, it has only been possible to explain the immediate atmospheric circulation anomalies preceding drought without adequate answers to the fundamental questions as to why these anomalous conditions persist, and what actually are the dynamic and thermodynamic forces which in the first place produce the anomalies in the general circulation of the atmosphere and their synoptic byproduct. It is also important to take into account local and regional factors of climate that may superimpose local climatic anomalies on the large-scale planetary circulation extremes.

The frequency and intensity of droughts in the marginal areas of Africa had led to the speculation that man himself may be inducing drought conditions through his careless interactions with his fragile environment. To this end, a number of hypotheses relating to human land-use have been propounded for droughts in Africa. Schnell (1976) suggested that the effect of the trampling of the soil and of overgrazing may affect the production of freezing nuclei. It was found that decaying debris may contain a kind of bacteria (Pseudomonas syringe) that serves as a remarkably efficient nucleus. Removal of the vegetation, therefore, removes a source of efficient freezing nuclei that could theoretically reduce the probability of convective rainfall from large cumulus cloud. Schnell's hypothesis can be easily discarded on the ground that other suitable nuclei may remain even if the soil is bare.

MacLeod (1976) who analysed the influence of the Saharan dust layer in relation to the structure of the ITD has postulated the introduction of dust into the atmosphere from denuded soil surfaces as a possible cause of drought. In between the moist, warm southwest monsoon air and the hot, dry northeast Harmattan air is usually a small region of low pressure trough into which the easterlies flow. The ITD is located at the southern edge of the trough (Fig. 1). It is in this region that cumulus formation (squall lines), resulting from the interaction of the southwest monsoon air and the northeast Harmattan winds, move east to west to produce the greatest rainfall in the Sahel.

During the 1974 drought, MacLeod (1976) observed that large amounts of dust in the Sahelian atmosphere produced an isothermal condition in the southwest monsoon which is the source of
precipitation in the region. He then postulated that such an isothermal character of the monsoon air will suppress any significant updraft and that there will be little mixing of the Harmattan wind with the moist, warm air because of the inversion formed by the dusty air. Cumulus cloud formation and rainfall along the ITD will consequently be reduced. Furthermore, the pressure of the dusty atmosphere would be reduced relative to that of a non-dusty air because of higher temperatures aloft. This would lead, in turn, to an increase in the size of the trough in which the easterlies flow. Consequently the northeast Harmattan winds should flow farther south and the southwest monsoon more gently north. That is, the ITD would be located in a more southerly position in sporadic and scanty rainfall in the Sahels as observed by MacLeod (1976) during the 1974 drought. Although it is difficult to generalise MacLeod's (1976) results because his hypothesis was based on observation from only Niamey, it is obvious that the presence of a dust layer can reduce the downward radiative flux while at the same time increase the heating of the atmosphere. This indicates a stabilizing effect of dust or the rate of lower level temperature decrease with height, leading to the stable layer inhibiting convection, thus preventing removal of the dust layer and perpetuating the thermally stable situation.

FIG. 1 REGIONAL ATMOSPHERIC CIRCULATION IN WEST AFRICA
Another plausible mechanism for drought occurrence may be the presence of an increase in the atmospheric particulate which may lower the surface temperature and permit an increase in mid-tropospheric subsidence which, in turn, opposed any convection (e.g., Bryson, 1973). However, the direction of such effects is still uncertain. In fact, Greenhut (1977) has shown that the rainfall in the Sahel tends to increase as the concentration of CO₂ and particulates matter in the atmosphere increase.

Perhaps the most celebrated drought causal hypothesis related to human land-use is the effect of changed albedo on rainfall; the albedo feedback hypothesis. Feedback is a process in which two (or more) variables are inter-related in such a way that a change in one evokes a change in the other, which in turn has an effect on the first. Feedback is positive if the change in the first variable is reinforced and is negative if the change is reduced. This hypothesis was first introduced by Oosterman (1974) who reasoned that the destruction of vegetation and exposure of soil would increase albedo, and hence lower surface temperatures. This would, in turn, reduce the heat input to the lower atmosphere, decrease lapse rate and hence lead to a decrease surface convection required for cloud formation and precipitation.

Charney (1975) independently postulated a similar biogeophysical feedback mechanism as tending to produce changes in rainfall and plant cover in areas which are stressed by human activities. An increase in surface reflectivity (albedo) will produce a relative cooling and, since the ground stores little heat, it is the air that loses heat radiatively. In order to maintain thermal equilibrium, the air must descend and compress adiabatically. The induced subsidence would in turn depress convection, reduce relative humidity and enhance the maintenance of desert-type climate. Studies with numerical models of the atmosphere have supported the hypothesis that changes in surface properties, such as reflectivity and soil moisture, may contribute to the persistence of drought in the Sahel. A good exposition of these models is given by Mitchell (1983) and it now appears from these models that the albedo effect is a key feedback mechanism in controlling sub-tropical and tropical African climate. Three cautionary remarks on the use of models must however be made. First, in order that the model's response may be distinguished from the fluctuations which are part of the model's natural variability, the imposed changes are made much larger, and more extensive than those observed recently during the Sahel drought. Second, many of the relevant physical processes are represented in the models in a very simplified manner. In addition, models testing the albedo feedback mechanism often represent a rather dramatic impact on the surface characteristics (e.g., increase in albedo by 20%) and heat budget of the earth over a small region. While it is quite probable that removing the vegetation from a semi-desert area may provide the stimulus to transform it into a true desert, the validity of the mechanism invoked for desertification tendencies by the theoretical numerical models has been questioned (e.g., Idso, 1981). It is quite apparent that the albedo-induced mechanism cannot be treated properly without more basic research into boundary-layer processes, especially soil moisture fluxes. Moreover, the fact that rains often return after a period of drought is an indication that other atmospheric mechanism may override the feedback effects of surface albedo changes. In general, while many causes of drought in Africa have been hypothesized, none has been conclusively proven.

Spatial and Temporal Characteristics of Drought Occurrence

Spatial Patterns

The African continent is a land of extreme contrasts in rainfall distribution, but its subregions are likely to be related to each other in many respects. Thus an understanding of the areal extent, duration and time distribution of drought periods on the continent would be useful in good water resources planning. Only a few investigations, however, have approached these
relevant aspects of drought study in Africa.

Nicholson (1980, 1981, 1986) divided Africa into 84 homogeneous rainfall regions on the basis of the mean rainfall, rainfall variability and length of the rainy seasons for a total of 1087 stations. A map of the 84 regions is given in Figures 2, above and Table 1 gives the approximate criteria used in West Africa for assigning stations to particular regions. Station data were transformed into normalized rainfall departures $X_{ij}$ expressed as
\[ X_{ij} = \frac{(r_{ij} - r_i)}{s_i}, \]  

(1)

In Eq. (1), \( r_{ij} \) is the annual rainfall total for the station \( i \) in the year \( j \), \( r_i \) is the long-term mean for the station, and \( s_i \) is the standard deviation of annual totals. For each region, a spatial mean departure was obtained as arithmetic average of all stations in the region. The 84 regionally averaged rainfall anomaly time series were then used to investigate recurrent spatial patterns of African droughts using a linear correlation method. Nicholson's (1980, 1981, 1986) analyses showed that African droughts displayed remarkable spatial coherence. That is, the entire monsoonal rainbelt tended to be affected in such a way that drought extended over much of the intertropical Africa simultaneously.

The spatial coherence of drought was particularly marked in the semi-arid regions of northern Africa, generally extending from across the east-west expanse of the continent and including areas with winter rains in the north and those with summer rains south of the Sahara. Such coherence has also been observed across the entire continent, especially on a scale of several years to a decade. For example, in the 1950's rainfall was above normal in 65 of the 84 rainfall regions, while below average rainfall was limited to the equatorial regions, such as East Africa. In the period 1968—1973, drought prevailed and rainfall averages for the six years were below average in 68 of the 84 rainfall regions; positive rainfall departures from the long-term averages were generally confined to the equatorial regions (Nicholson, 1986). Motha et al., (1980) have also shown that precipitation patterns in West Africa displayed some evidence of recurrent spatial patterns which indicated a strong tendency for covariability over a large area.

Other analyses (e.g. Gregory, 1982; Klaus, 1978; Melice and Wendler, 1984; Ogallo, 1988; Palutikof et al., 1982) used the technique of principal component analysis (PCA) to examine the recurrent spatial patterns of rainfall anomalies (drought/flood) in Africa. PCA is a simple data-descriptive method which can be used to provide data reduction and to identify characteristic, recurring independent modes of variation within a large data set (see e.g. Harman, 1976). The analysis sorts initially correlated data into a hierarchy of statistically independent modes of variation which explain successively less and less of the total variation (Eder et al., 1987). The analysis of Gregory (1982), Klaus (1978), Melice and Wendler (1984), Ogallo (1988) and Palutikof et al., (1982), showed that, in opposition to the conclusion of Nicholson (1980, 1981, 1986), the spatial variability of drought occurrences in Africa is very high.

In general, it is quite seldom for significant drought to affect large parts of Africa simultaneously although some sub-regions (e.g. Sudan-Sahel and the Horn of Africa) tend to more persistently catch the brunt of drought on a year-by-year basis than others. Sale (1988) and Umar (1988) have similarly shown that large-scale droughts do not frequently cover northern Nigeria (6°26'N-13°50'N and 3°22' E—9°35' E) as a whole. Indeed the occurrence of large-scale droughts seems to be the exception than the rule, with distinct spatial differences dominating the wet and dry years. Figure 3 shows the percentages of the subareas of northern Nigeria affected by extreme and moderate droughts, normal, wet and very wet conditions for each of the years in the period 1927—1983. An examination of Fig. 3 below and the annual maps of different moisture conditions presented in Sale (1988) and Umar (1988) suggest: that the patterns of dryness and wetness in northern Nigeria are remarkably noisy with the length and severity of drought varying from subarea to subarea on yearly basis. In the broadest sense, drought does not often cover the entire region, and no particular area is consistently affected. Thus drought occurrence in the region is largely spatially incoherent with the area of moderate to severe drought changing markedly in size and position from year to year. This apparent lack
Fig 3: Percentages of areas in Northern Nigeria having different moisture conditions in the period 1927—1983.
of large-scale regional preferences in the spatial patterns of drought in Africa is comparable to the patterns of drought occurrence over the Great Plains of America (Oladipo, 1986).

Because most rainfall in tropical Africa comes from convective clouds, rainfall tends to be highly variable in time and space. Consequently, one expects that the spatial changes in drought will follow similar highly variable patterns. In this respect, one may argue that it is quite seldom that drought would extend over much of Africa simultaneously. The use of areal-averaged departures from normal rainfall to delineate the spatial changes of drought may, therefore, be misleading since important regional details may be obscured by spatial averaging. In looking for recurrent patterns of drought, it appears more realistic to use a dense network of single station records than regional averages. Such an approach would enable us to identify homogenous areas of drought incidence, and areas which experience favourable conditions when others experience drought and vice versa.

Trends and Periodicities

There has been considerable debate as to whether a given pattern of drought may persist from one year to the next and whether is cyclical. To this end, a large number of time series analyses using only rainfall as the basic data have been carried out (e.g. Tyson et al., 1975; Landsberg, 1975; Bunting et al., 1976; Rhode and Virji, 1976; Klaus, 1978; Motha et al., 1980; Ogallo, 1979, 1981, 1982, 1984, 1986 and Dennett et al., 1985) to examine trend and periodicities in drought occurrence. Others (e.g. Nicholson, 1980, 1981, 1983a, 1986; Nicholson and Entekhabi, 1986) have used simple drought indices such as annual rainfall departure series of Eq. (1). The area-average departure time series for four zones in the West African region is given in Figure 4. The high degree of variability in the seasonal rainfall of this region is readily apparent and all the four zones show similar features. The graphs show that during the period preceding 1950, the amount of seasonal rainfall was generally highly variable, and the brief drought periods of the 1910s and 1940s alternated with periods of copious moisture conditions. Beginning in about 1950, a period of above normal rainfall conditions prevailed. Ten years later (c.1963) decline in rainfall began in the Sahel and in the late 1960s in the Sudano-Guinean belt. There was severe drought in the early 1970s followed by some recovery in 1974 and 1975. In the later seventies and early eighties, however, drought returned with various intensities from year to year.

![Graph showing rainfall departures for four sub-Saharan zones from 1900 to 1980](image)

Fig. 4: Standard annual rainfall departures for four sub-Saharan zones 1900—1980 (From Nicholson, 1983)
The downward trend in the rainfall culminating in the beginning of drought since 1968 in the main sub-Saharan belts (Fig. 4) is particularly remarkable. The unprecedented length and severity of the recent drought compared with other droughts of the instrumental period have led some investigators (e.g. Kraus, 1977; Katz, 1978; Ogallo, 1979; Walker and Rowntree, 1977) to examine the extent to which the occurrence of a dry year is a signal of a following dry year or years in Africa. The preceding of a dry year by another dry year is a form of persistence and it is one of the baffling problems of drought study. For a group of stations in the Sahelian and Sudanian zones of West Africa with mean annual rainfall of 400—1000 mm and for the period 1911—1974, Walker and Rowntree (1977) found eight runs of two years above or below median rainfall, one of the five years, two of seven years and one of ten years. The probability that such persistence would occur randomly was found to be low (9 per cent). That is, there is a distinct tendency in the Sahel for abnormal wetness or drought to persist from one year to the next or succeeding years.

In a similar manner, Kraus (1977) gave some evidence of the occurrence of long runs of wet and dry years for sub-tropical Africa. On the other hand, other analyses (e.g. Katz, 1978; Ogallo, 1979, 1984) produced no evidence of any statistically significant persistence of sub-tropical African droughts. There was only a slight statistical evidence to support a long term trend in rainfall time series, especially since the 1960s in the Sudan-Sahel region when the degree of multi-year persistence of drought seemed to have increased (see Dennet et al., 1985; Nicholson, 1983b). Even then only some individual stations showed significant trend and their number was not more than what can be expected by chance. For example, Ogallo (1979) found significant trends in only four of the sixty-nine rainfall time series he analysed. In general, most of the trends observed in some of these African rainfall series were small compared with their year to year variability, and the possible trend in the decline of rainfall seemed to be affected only by the recent years. Therefore, one may argue, as did Oladipo and Hare (1986) that drought persistence which may appear to be highly significant over short time spans (e.g. Nicholson, 1983b) are unlikely to be stable over long time spans.

Many attempts have also been made to discover statistically significant cyclical behaviour in the time series of precipitation and other water-resource variables related to drought in Africa (e.g. Tyson, et al., 1975; Rodhe and Virji, 1976; Kraus, 1978; Ogallo, 1979, 1982, 1984, 1986; Nicholson and Entekhabi, 1986). The general conclusion from these studies is that there is no statistically significant evidence of large amplitude regular cycles. Rather, the drought indices time series are dominated by weak quasi-periodic fluctuations around 2.2 — 2.8 years, 3 — 3.7 years, 5 — 6 years, 10 — 13 years and, seldomly, 30 years. This large range in the spectral bands indicate instability of the observed quasi-periodic fluctuations, and the cycles explain only a very small proportion, that the period of measured data in Africa is rather too short to establish a firm cyclicity in drought occurrences. Because of this quasi-periodic behaviour of African drought, any extrapolation of cycles for forecasting may not be successful.

Measures for the Amelioration of Drought

Although drought cannot yet be predicted, and although no practical method of enhancing precipitation appreciably is yet available, there are many measures which can be used to alleviate effects of droughts. Drought mitigation measures may take two forms: short-term emergency measures and long-term measures intended to reduce drought impacts (see Rosenberg, 1980 for details).

In general, short-time remedial steps that could be taken after the onset of drought may include strategic irrigation (making maximum effective use of limited water supplies), matching crop selection and management with the moisture supply, adjusting livestock numbers, con-
structing new wells, boreholes and stock ponds, intensifying dissemination of information on drought mitigations and drought compensation. Perhaps the most effective short-term drought mitigation measure is that of preparing and disseminating practical advice to farmers about adjustments they can make when drought has struck. In Africa, dissemination of information about drought has always been on a very local scale with no evidence of inter-regional cooperation. While some country extension services (e.g. Agricultural Extension Research and Liaison Services, Zaria, Nigeria) and other agencies that are listed in Farmer and Wigley (1985) do issue newsletter and radio and television programs containing advice on water and livestock management, their activities still lack the coherence required for regional information about drought in Africa.

Long-term technological measures may include minimum tillage, large-scale irrigation scheduling, weather and microclimate modification, alternate crops, improved cultural and agricultural practices, water harvesting, soil evaporation reduction, selected plant breeding for drought tolerance and small water impoundments. The relevant of these long-term remedial steps in our drought-prone areas is water harvesting which involves the capture of rainfall in created depressions within fields or in stream flood plains for use in agriculture. On large-scale basis, water may be transferred from the adjoining areas of water surplus to the drought affected areas of water deficit.

For the longer term there are other remedial steps which can use climatic knowledge to mitigate drought (see WMO, 1983 for details). One step is to develop the probability distribution of rainfall amount and timing from existing series of observed data. These distributions will provide information on the beginning, the end and length of the rainy season and on the amount of available water during the season. Such knowledge is pertinent to the introduction of new, more productive, and more drought resistant varieties of different crops, for the introduction of improved farming systems and for the choice of appropriate agricultural machinery.

Another practical measure to mitigate drought's effects is the use of significant spatial and temporal characteristics of the past droughts to serve as indicators of their future patterns of occurrence. Spatial analysis would involve the construction of maps of drought occurrence in each growing season, extending as far back as records permit. The maps can then be used to identify recurrent patterns: for example, homogenous areas of drought incidence, and areas which experience favourable conditions when others experience drought and vice versa (e.g. Palutikof et al., 1982). The temporal characteristics of drought can be examined by the well-known time series analysis techniques (see, e.g. Oladipo, 1988) in order to detect significant periodicities in the drought indices time series of the past. These periodicities can then be useful for predicting the possibilities of future droughts as attempted for South Africa by Dyer and Tyson (1977).

The establishment of an early warning system to detect meteorological drought and provide input into agricultural drought is another practical mitigation measure that is long overdue in Africa.

Planned farming and land use, especially in the marginal and sub-marginal zones, so that the life styles and support systems can be adaptive to the nature of their climate and fragile ecosystems in another long-term measure that could be taken to reduce drought impacts.

The tragic events of 1983-1984 in many parts of Africa, as a result of the recent droughts, indicate that drought mitigation strategies are absent in most parts of the continent. So far, much of the short-term measures to combat drought have depended mostly on ad hoc relief operations. Relief per se, however, does not provide protection; it does not prevent drought disasters from recurring in the future. The extreme dependence of many of the affected states on donations from international agencies suggests that there is no prominent systematic attempt to
ready the countries for drought emergency by combining available technological, economic and societal tools into strategies. Some of the short-term technological solutions to drought that are often sought may even make the drought-prone marginal areas of Africa more vulnerable to the impacts of drought. For example, indiscriminate construction of dams and boreholes without much attention to pasture resources, without adequate appraisal of the water potentials being tapped, without extension of a balanced ecological approach and without establishing control over the use of water may aggravate the problems of drought such as the lowering of water table and the deprivation of water to farmers who depend on the natural courses of rivers.

Similar to the short-term measures, most of the enumerated long-term drought mitigation measures have not been widely adopted in Africa. While large-scale irrigation schemes are available in many parts of Africa their inability to cope with the water requirements for adequate food production is reflected in persistent food shortages in many regions in times of drought. Moreover, most of the meteorological approaches to long-term drought mitigation, discussed in the preceding sections, have not been widely adopted. There are only few attempts (e.g. Nicholson, 1978, 1980, 1986; Nicholson and Ertekhabi, 1986; Ogallo, 1984, 1986) made to put drought occurrence in Africa into its proper spatial-temporal dimensions and, even then, only the works of Nicholson cover the whole of the continent. Seasonal arid within-season crop forecasting that can lead to very early warning and crop failures are just being introduced in Niger, Senegal, Tanzania, Ethiopia, Lesotho and Kenya (see Farmer and Wigley, 1985 for details). Further work is clearly warranted in the spatial temporal pattern assessment of drought and the development of early warning methods.

Conclusion

The conclusions, as evidenced from this review, are presented as follows:

(i) Drought is an inherent characteristic of Africa, especially in the semi-arid regions. The drought in Africa which began in 1968 has not yet ended even by 1983, especially in the Sahel. In recent years drought has spread to southern Africa and some parts of eastern Africa, although recent heavy rains have provided some relief.

(ii) In general, drought seldom covers the entire African region and no particular area is consistently affected. Select areas do catch the brunt of drought on a year to year basis but the high degree of incoherence in the spatial distribution makes it difficult to predict which region or regions will be affected.

(iii) Similarly, no known significant periodicities or trends exist in the climate of Africa which cause or ameliorate drought. Although rainfall amounts in the Sub-Saharan, have indeed markedly decreased over the last 15 years, there is no certainty that these deficiencies will continue or cease. The spectral behaviour indicates that drought in Africa has a large random component. The quasi-biennial, quasi-triennial and quasi-five year cycles are common features of the African drought series. These periodicities are nonetheless spatially sporadic; they can be evident at one station while being absent at another a few hundred kilometers away. In this respect, significant peaks are only short-lived time variabilities in drought as recorded by individual stations and do not represent any persistent regional drought characteristics. Qualitative interpretation of the observed cyclic variation in some drought series must, therefore, still remain ambiguous.

(iv) No known method exists to reliably predict the continuation, cessation or recurrence of drought in Africa.

(v) The general conditions necessary for the formation of drought are well known to meteorologists but the specific quantitative conditions essential for the onset and cessation of the African drought are not yet fully understood. Further developments to explain the causal
mechanisms are required. The role of large-scale climatic modelling is, however, uncertain in this area because general circulation models have their greatest failings when the climatic state is most deviant from normal, for example, during drought. Moreover, if drought is a result of the climate system's response to well-defined external factors, one would expect its temporal patterns of occurrence to be very similar to one another. The rather incoherent geographical scales of drought occurrence and its periodic behaviour suggest that drought is more likely the result of the long-term response of the climate system to short-period stochastic forcing which includes dynamic, energetic and radiative mechanism. In this respect, drought could be modelled as stochastic perturbations by the interactions of non-linearities internal to the climatic system of Africa (e.g. Nicolis, 1982). The best hope for progress, however, probably lies in a combination of empirical, statistical, theoretical and modelling methods to account for most of the well-known characteristics of drought that have been elucidated in this paper.

Drought will continue to affect Africa, but the extent and time of occurrence may be difficult to monitor because of its remarkable changes in size and position from year to year. Therefore, the search for simplistic scientific explanations from sketchy analyses for drought must stop and a better approach that considers the complexities of Africa's climate in understanding the nature and pattern of occurrence of drought need to be encouraged. A complete understanding of African climate and conclusive knowledge of the possible impact of mankind and environment on the continent's climate requires continuous monitoring of the system. Unfortunately this approach is still at its infancy in Africa.

Because no two droughts are the same and because their impacts vary geographically, no single mitigation strategy would be adequate. A mixture of strategies must be available and drought control plans must be of an interdisciplinary nature considering the intimate interactions of social, economic and political factors that determine drought impacts. Implementation of these strategies will require supporting research, local and regional co-ordination for a joint assessment of the experience of the last droughts and of their plans for dealing with any recurrence. Such a cohesive effort can lead to a better understanding of the available technology about water transfer from areas of surplus to areas of persistent moisture deficit. The initial cost of such a venture would be large but this could still be trivial when set against the cost of drought.

In the final analysis, it should be obvious to various African governments by now that there is a need for the establishment of drought research monitoring and planning units comprising economists, agriculturalists, hydrologists, experts in human sciences and health services, and many others as well as meteorologists. To this end, Nigeria can take the lead by establishing an Institute for Drought Research and Monitoring to formulate a coherent predisaster plan for mitigating the impacts of drought. Such an institute could be charged with the responsibilities of providing a complete understanding of the total environment (e.g. climatic, economic, social etc.) of the drought-prone areas and serving as a central agency where all reports on rainfall, river flows, crop development, the state of livestock and other relevant information about drought can be rapidly analysed and disseminated to the public. Simple and haphazard approaches to this climactic nemesis (drought) should stop. Drought in Africa is an African problem and it requires the cohesive efforts of all the affected countries to combat its impacts. Until such is done, Africa will always be vulnerable to the devastating effect of drought.
References


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EFFETS DES CHANGEMENTS CLIMATIQUES SUR LES SYSTEMES AGRICOLES
ET ECOLOGIQUES D'AFRIQUE SUB-SAHARIENNES.

Sally, Sénégal. 11 au 15 Septembre 1989

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Un exemple des Effets des Activités Humaines sur
l'Environnement Togolais : l'Erosion côtière

par

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Introduction

L'environnement terrestre est en pleine mutation ; et très souvent, on attribue les changements de l'environnement à des activités humaines sur la Terre. Ces dernières années, les médias ont pris la vedette sur les revues scientifiques en matière de "changement global de l'environnement mondial."


BROWN, FLAVIN et POSTEL rapportent qu'en Septembre 1988, les 2/3 du BANGLADESH étaient inondés ; suivant les analyses, ce phénomène serait dû à un changement intervenu dans le cycle hydrologique des basins de l'Himalaya à cause des problèmes de déforestation des dernières décennies.

En Mars 1989, la NASA révéla la diminution de la couche d'ozone. Plus de 100 chercheurs de 7 pays ont passé 16 mois à analyser les données disponibles (mesures au sol et par satellite) et ont trouvé qu'entre 1969 et 1986, la diminution de l'épaisseur de la couche d'ozone dans l'hémisphère Nord a varié entre 1,7 à 3%.

Quand bien même les chiffres sont souvent sources de désaccord entre les chercheurs, la tendance générale dans les conclusions de leurs travaux est l'augmentation de la température moyenne mondiale des années 80.

La nouvelle approche dans les recherches sur les effets des activités humaines sur l'environnement tend à voiler les problèmes locaux ou régionaux très graves auxquels les pays en développement doivent faire face.

Dans le cadre du présent atelier, nous avons présenté la tendance de deux paramètres climatiques du Togo : la température et la précipitation. L'érosion côtière qui est un problème environnemental que vit le Togo depuis plus de deux décennies a été présentée. Enfin la Perspective de recherche, fait l'ébauche du programme de recherche que le département du Génie Civil à l'ENSI, Université du Bénin se propose de mener dans le cadre de la préservation de l'environnement côtier du Togo.
Quelques données climatologiques du Togo : les températures et les précipitations

La figure 1 présente les stations météorologiques du Togo ainsi que sa situation géographique. Le Togo est situé dans l'hémisphère Nord, en Afrique Occidentale ; il s'étend :

- en latitude entre le sixième et le onzième parallèles, soit une longueur de 556 Km à vol d'oiseau ;

- en longitude, entre le méridien Greenwich (méridien 0°) et le méridien 1°40' Est.

Au Togo, et d'une façon générale dans la zone intertropicale de l'Ouest Africain en général, les moyennes des températures maximales augmentent du Sud vers le Nord, tandis que celles des températures minimales diminuent dans le même sens.

Selon ATTIGNON, de part et d'autre du parallèle de Blita, règnent deux régimes pluvieux :

- au Sud, un régime de type équatorial avec deux saisons pluvieuses (la grande saison des pluies de Mars à Juillet et la petite saison des pluies de Septembre à Octobre);

- au Nord, un régime de type tropical caractérisé par une seule saison des pluies d'Avril à Octobre.

Le Sud Togo connait une anomalie climatique caractérisée par une faible précipitation annuelle moyenne par rapport à sa position géographique qui devrait lui conférer un climat équatorial (au moins 1500 mm de pluie au lieu de 877 mm).

Le tableau 1 présente les moyennes mensuelles des précipitations et des températures à Mango et à Lomé Aéroport. Afin d'étudier l'évolution de ces paramètres dans le temps, nous avons calculé leurs valeurs annuelles en utilisant les relevés des 40 dernières années. Les précipitations sont des totaux annuels alors que les températures sont des moyennes annuelles obtenues par la formule :

\[ T_j = \sum a_i t_{ij} \]

avec :

- \( a_i \) = coefficient égal au rapport du nombre de jours dans le mois au nombre de jours de l'année ;

- \( t_{ij} \) = température (minimale, moyenne, maximale) du mois \( i \) de l'année \( j \) ;

- \( T_j \) = température (minimale, moyenne, maximale) moyenne de l'année \( j \).
Légende :
△ Station principale
⊙ Station d'observation
□ Poste climatologique
● Poste pluviométrique
<table>
<thead>
<tr>
<th>Station</th>
<th>Paramètre</th>
<th>Janvier</th>
<th>Février</th>
<th>Mars</th>
<th>Avril</th>
<th>Mai</th>
<th>Juin</th>
<th>Juillet</th>
<th>Août</th>
<th>Septembre</th>
<th>Octobre</th>
<th>Novembre</th>
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<td>61.56</td>
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<td>235.06</td>
<td>87.86</td>
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<td>22.48</td>
<td>23.77</td>
<td>24.22</td>
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<td>23.33</td>
<td>22.57</td>
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<td>26.77</td>
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<td>27.16</td>
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<td>24.87</td>
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<tr>
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<td>32.32</td>
<td>31.97</td>
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<td>29.99</td>
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<td>29.03</td>
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<td>4.31</td>
<td>27.06</td>
<td>61.75</td>
<td>111.45</td>
<td>141.16</td>
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<td>25.18</td>
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<td>21.60</td>
<td>19.55</td>
<td>17.96</td>
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<td>31.20</td>
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<td>37.78</td>
<td>38.83</td>
<td>37.43</td>
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<td>30.97</td>
<td>33.8</td>
<td>36.13</td>
<td>35.39</td>
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</tbody>
</table>

- Moyennes calculées utilisant les 40 dernières années.
Les résultats de ces calculs sont représentés sur les figures 2 et 3. Quand bien même les courbes de température ne démontrent pas une tendance nette, on peut remarquer en considérant les températures moyennes annuelles que 1987 est l'année la plus chaude aux deux stations considérées.

Le tableau 2 montre les 5 années les plus chaudes à chacune des stations.

**Tableau 2 : les 5 années les plus chaudes à Lomé et à Mango.**

<table>
<thead>
<tr>
<th></th>
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<td>Année</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td>Température*</td>
<td>28,39</td>
<td>28,43</td>
<td>28,45</td>
<td>28,37</td>
<td>28,80</td>
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</table>

* Température moyenne annuelle


Ces dernières années, la capitale togolaise a présenté un spectacle d'inondation déplorable à chaque saison des pluies (Mars-Juillet). Compte tenu des nouvelles données par les médias sur les changements climatiques, on pourrait être porté à croire à une augmentation dans la précipitation annuelle. Les courbes de la figure 3 montrent plutôt que les précipitations des années 80 fluctuent autour des moyennes annuelles, 877 mm pour Lomé et 1112 mm pour Mango. Les problèmes d'inondations pourraient plutôt être liés à un changement probable dans l'intensité des pluies (pluies mensuelles ou journalières), à la succession des périodes pluvieuses et surtout au taux accéléré de l'urbanisation de la ville.
Fig. 2 : Les Températures annuelles à Mango et à Lomé

Températures minimales, moyennes, maximales: MANGO

Températures minimales, moyennes, maximales: LOME - AEROPORT
Fig. 3 : Les précipitations annuelles à Mango et à Lomé

Précipitations : MANGO

Précipitations : LOME-AEROPORT
L'érosion côtière au Togo

Depuis la construction du Port Autonome de Lomé, la côte togolaise est sous l'effet d'un déséquilibre sédimentologique. En 1979, un séminaire-atelier a été tenu à Lomé sur les problèmes d'érosion littorale au Togo et au Bénin.

En fait, l'érosion de la côte togolaise fait partie de celle de tout un secteur de l'Afrique de l'Ouest, allant de l'embouchure de la Volta (Ghana) à Cotonou (Bénin); figure 4. C'est ce secteur qui a été le plus étudié de toute l'Afrique de l'Ouest compte tenu de l'ampleur que le phénomène y a prise. Devant l'accélération du processus de l'érosion au début des années 80, le Gouvernement Togolais, avec l'aide du Ministère Français de la Coopération, a mis en place à l'Université du Bénin, une équipe de recherche sur l'érosion côtière. Dans ce qui va suivre, nous allons essayer de décrire le phénomène, de présenter les solutions qui ont été proposées et enfin résumer les causes de l'érosion.

A l'Ouest de la jetée Ouest du Port de Lomé, figure 5, on a constaté un engraissement de la côte qui a avancé d'environ 450 m en 10 ans. D'après les études de NEDECO, le taux de progression du trait de côte, à 2 Km de cette jetée est de 60 m/an pour la période de 1964-69, 28 m/an pour 1969-73 et de 18 m/an pour 1973-75. En 1988, l'avancement de la côte est de 900 m à l'Ouest de cette jetée et d'environ 70 m à l'ancien wharf de Lomé. Il faut toutefois signaler qu'en Août 1976, à environ 6,5 Km à l'Ouest du port, on a observé une érosion qui s'est produite sur environ 800 m de longueur, ce phénomène s'est repété durant certaines des années 80. Complice du sens de la dérive littorale, on n'a pas pu à priori relier le phénomène à la construction du port. Cependant, dans une conférence récente, le Professeur Rossi a avancé l'hypothèse que l'érosion à ce endroit a pu être provoquée par un courant induit par la réflexion des houles sur la jetée Ouest du Port.

La côte à l'Est du Port de Lomé a été l'objet d'une érosion exceptionnelle. De 1964 à 71, le recul moyen est d'environ 15 m/an sur une distance de 4 Km environ. Le taux de recul décroit ensuite pour devenir pratiquement nul à environ 6 Km à l'Est du Port. Durant la période 1971-72, le beach-rock (grès de plage) apparaît dans ce secteur et la vitesse de retrait de la côte gagne en direction de l'Est. La zone affectée s'étend sur 8 Km de côte. Dans le même temps, un iéger engraissement est observé à Kpémé et à Aného. En 1977, le phénomène affecte environ 15 Km de côte et l'affouillement maximal a été durant la période 1973-75.
Fig. 4 : CARTE DE SITUATION DU LITTORAL
DU GOLFE DU BÉNIN

LEGENDE

1. Port de Lomé 6°
2. Wharf de Kpémé
3. Port de Cotonou

OCEAN ATLANTIQUE

Sabies des Cordons Nougkottien
Plateau (Mio-pliocène)

0 10 20 km
Fig. 5 : EVOLUTION DE LA COTE APRES CONSTRUCTION DU PORT DE LOME
Entre 1975 et 1980, la côte recule en moyenne de 0,66 m/an dans le secteur située à 4 Km du port et où le beach-rock est complètement dégagé. Le recul maximal alors supérieur à 20 Km /an se situe entre 7 et 8 Km du port, à Tropicana ; la zone en érosion s'étend sur près de 19 Km. La zone entre Agbodrafo et Aného retrouve un équilibre relatif et il n'y a plus de secteur où l'on observe un engraissement net, hormis les variations saisonnières normales. Il faut toutefois noter la mise en évidence dans cette période de deux points d'érosion (le pied du wharf de Kpémé et en face de l'Eglise St Pierre et Paul d'Aného) où il y a concentration de houles orthogonales.

Depuis 1980, à l'exception des reculs ponctuels dus aux tempêtes, la côte togolaise est stabilisée sur les 5 premiers kilomètres à l'Est du port. A Tropicana, le beach-rock est dégagé depuis 1982 ; ceci a eu pour conséquence de réduire le taux de recul annuel à moins de 0,66 m/an. Par contre, à Kpogan, en un an (Septembre 1983 à Septembre 1984), le retrait de la côte a été de 42 m. De 1980 à 1984, l'érosion a gagné toute la côte togolaise. Toutefois, son intensité est plus prononcée dans certaines zones où il y a concentration des houles orthogonales comme à :

- Kpogan, déjà mentionné
- Kpémé où il y a eu un recul de 15 m en 24 heures, an Mai 1984
- Aného, devant l'Eglise St Pierre et Paul.

En 1984, le beach-rock s'est dégagé de Lomé jusqu'à Kpémé où il n'existe pas (*). De 1985 à 87, date à laquelle des travaux de protection ont commencé à Aného et à Kpémé, la stabilité relative de la côte s'étend jusqu'à Tropicana (8 Km du port de Lomé). Mais, le recul s'accentue de Kpogan (20 Km du port) à Kpémé, sauf à Agbodrafo où la côte est stable sur près d'un kilomètre. L'érosion reste importante entre Kpémé et Aného, à l'exception d'un secteur à peu près stable à Niessi, à l'entrée de la ville d'Aného. Actuellement, l'érosion se manifeste avec force dans des zones spécifiques comme le montrent les photos de la figure 6.

Nous venons de voir comment la côte togolaise a fait l'objet d'un bouleversement sédimentologique depuis 1964. Nous allons maintenant présenter les solutions proposées pour contrôler le phénomène et si possible l'arrêter là où cela est possible.

* L'absence du beach-rock à Kpémé a été expliqué par G. Rossi (1988) et A. Blivi (1988). D'après leur théorie, il existait une ancienne embouchure d'une rivière côtière à Kpémé ; cette zone constituait alors un milieu en perpétuel
Fig. 6 : Quelques vues de l'érosion de la côôte togolaise.

Photo 1 : La plage a complètement disparu à Kpogan. En Janvier 1988, un tronçon de la route internationale longeait en cette côte.

Photo 2 : Boboli Kope, entre Tropicana et Kpogan. L'escarpement dépasse 1,5m. L'éboulement se produit après.

Photo 3 : Tropicana; la force de l'érosion est telle qu'un brise-lames construit à l'Est de l'épí de Tropicana est détruit au 2/3.

Photo 4 : Goumou Kopé; à certain endroit, le ruissellement de surface contribue au phénomène de l'érosion.
mouvement, ce qui n'est pas approprié à la formation du
beach-rock.

Les solutions retenues pour la lutte contre l'érosion de
la côte togolaise ont été étudiées par le Projet Erosion
Côtière de l'Université du Bénin en collaboration étroite
avec le Laboratoire Central d'Hydraulique de France (LCHF),
aujourd'hui intégré à SOGREGAH. Le souci qui a dirigé la
démarche des concepteurs se résume dans le passage suivant de
Rossi (1988):

"Des absolus économiques, sociaux
et politiques obligent à adopter des
attitudes différentes, contraires,
parfois, à la stricte logique scienti-
ifique car celle-ci s'appuie sur des
echelles de temps sans commune mesure
avec le cadre temporel dans lequel
s'inscrivent les préoccupations
quotidiennes des populations et de
leurs dirigeants."

La découverte du beach-rock le long de la côte du golfe du
Bénin a servi de base fondamentale dans la recherche des
solutions aux problèmes d'érosion du littoral togolais. En
1980, le beach-rock est dégagé sur une longueur de 8 km à
l'est de la contre-jetée du port et l'on a remarqué que le
trait de côte se stabilisait à une distance de 30 à 60 m en
arrière du beach-rock. En 1984, il affleurait sur toute la
côte togolaise à l'exception de Kpémé où il n'existe pas. Le
LCHF a effectué des essais sur modèle réduit et qui ont
montré que dans les conditions hydrologiques du golfe du
Bénin, l'utilisation du beach-rock comme moyen de défense
contre l'érosion, sera efficace lorsque sa largeur est
supérieure à 10 m et son altitude au-dessus du zéro
hydrographique est d'au moins 1 m. Lorsque l'altitude du
beach-rock atteint + 1,5 m hydro et que sa largeur est
supérieure à 25 m, l'effet recherché est immédiat et la
stabilisation de la côte est obtenue au bout de quatre ans.
Ceci s'explique par le processus de transfert des sédiments
normalement à la côte sous l'effet des houles observées.

La solution proposée par l'Université du Bénin/LCHF pour
la protection de la côte consiste à l'utilisation du beach-
rock là où il est dégagé avec des structures artificielles à
Kpémé et à Aného où l'on ne peut compter sur l'usage du
beach-rock.

L'aménagement adopté pour protéger la ville d'Aného se
compose d'un brise-lames en face de l'Église ST Pierre et
Paul, là où il y a une concentration de houles, avec une
série d'épis à l'Est du brise-lames. Un système d'épis a été
proposé pour la protection de l'usine de traitement de
phosphate à Kpémé. La première phase des travaux a eu lieu en
1987 et a coûté 3 milliards de francs CFA.
La présentation des solutions de lutte contre l'érosion de la côte togolaise avant l'exposé des causes n'a pas été un hasard. Ce choix vient du fait que les travaux de protection eux-mêmes contribuent au phénomène d'érosion, devenant par là même des causes.

Les études existantes ont fait ressortir clairement que la construction de la jetée Ouest du Port Autonome de Lomé est incontestablement la cause principale du déséquilibre sédimentologique que connaît la côte togolaise depuis l'Est du port jusqu'à Aného. En effet, la construction de la jetée a interrompu la dérive littorale, causant ainsi la création d'une zone de dépôt en amont à l'Ouest et une zone d'érosion à l'Est.

Pendant longtemps, on a considéré la construction du barrage d'Akossombo comme étant l'un des facteurs de l'érosion de la côte togolaise. Même si aujourd'hui il est reconnu que le rôle de ce barrage est pour le moment négligeable dans les causes de l'érosion togolaise, des études ont montré que la construction du barrage d'Akossombo a joué un rôle de premier plan dans la destruction de la ville de Kéta.

L'ampleur actuelle de l'érosion à Goumou-Kopé et à l'embouchure de la lagune d'Aného est due à la construction des épis utilisés pour la protection de la côte (Figure 7). En effet, lorsque la houle est obligée de contourner un obstacle, les crêtes des vagues tournent autour de l'extrémité de l'obstacle et très souvent pénètrent à l'arrière de ce dernier. D'une façon générale, la protection d'une zone de côte en érosion limite les sources d'alimentation de la dérive littorale, accroissant par là le pouvoir d'érosion sur les parties non protégées.

On peut donc remarquer que l'érosion de la côte togolaise est due aux actions de l'homme qui modifie l'équilibre relatif de l'écosystème. Nous devons cependant faire remarquer qu'un autre facteur de l'érosion côtière est la remontée du niveau marin. Des études ont révélé qu'une surélévation de 1 à 2 mm du niveau de la mer peut induire un recul du trait de côte de plusieurs dizaines de centimètres par an ; or les activités humaines tendent à accélérer la remontée du niveau marin.

L'importance du rôle de la jetée du port de Lomé tend à minimiser l'effet des autres causes probables dans le processus d'érosion de la côte togolaise.
Fig. 7 : Les effets des épis (ouvrages de protection).

Photo 5 : Embouchure de la lagune d'Aného. L'effet de l'épi de tête (érosion à l'aval) a provoqué l'ouverture de la lagune d'Aného sur l'Océan.

Photo 6 : Goumou Kopé; la construction du dernier épi (épi de tête de la série d'épis protégeant Kpémé) a accentué l'érosion vers l'Est de Goumou Kopé.
Perspectives de recherche

Parmi les problèmes de l'environnement qui se posent au Togo, l'érosion côtière est l'un des plus importants. Le gouvernement togolais fait beaucoup d'effort pour contrôler et si possible maîtriser le phénomène. Il a investi 3 milliards de francs CFA pour la protection de Kpémé et Aného.

Avec l'aide du Ministère Français de la Coopération, le Projet Erosion Côtière à l'U.B. a établi un programme de suivi de l'évolution de la côte (relevés topographiques et batymétriques de la côte ; analyse de l'altération du beach-rock).

Le Département de Génie Civil à l'Ecole Nationale Supérieure d'Ingénieurs entend apporter sa contribution à la recherche de solutions viables et moins coûteuses aux problèmes d'érosion.

- Un axe de recherche vise la récolte d'autres données physiques telles les mesures du transport solide par les courants et les vagues ainsi que la modélisation mathématique de la côte ;

- Un autre axe vise la recherche de structures de protection de côte qui utiliseraient des matériaux locaux, tels le sable et le gravier.

Outre les collaborations nationales et régionales, nous travaillons avec la SOGREAH et nous venons de prendre contact avec le "Coastal and Oceanographic Engineering Department" de l'Université de Floride à Gainesville.

Conclusion

Dans sa quête d’un devenir meilleur, l’homme modifie continuellement l’environnement dans lequel il vit. Ces modifications détruisent souvent l’équilibre déjà fragile des écosystèmes. La réaction de l’environnement marin aux interventions humaines à conduit aux problèmes d’érosion que la côte togolaise connaît depuis plus de 2 décennies.
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EFFETS DES VARIATIONS CLIMATIQUES SUR LA PRODUCTION DU MIL

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PAR MADIAGNE DIAGNE

ISRA/SENEGAL

Le mil est la céréale de base au Sénégal. Elle occupe la plus grande partie des surfaces emblavées et entre pour une grande part dans l'alimentation de la population.

Cette importance a fait qu'elle a retenu l'attention de la recherche qui a mené nombre de travaux pour en améliorer la productivité.

Les résultats obtenus ont permis de vulgariser de nouvelles variétés et techniques de cultures.

Pour la bioclimatologie les connaissances acquises ont permis de mettre au point et de valider un modèle de simulation des bilans hydriques.

Cet outil méthodologique permet de faire :
- Un zonage agroclimatique
- Un suivi de la campagne de production et une prévision des rendements.

Une bonne prévision des rendements:
LE MODELE DE SIMULATION

Il est basé sur la solution par période de 5 jours de l'équation du bilan hydrique

\[ P + I + R + Dr + E + TR + \Delta s = 0 \]

Le modèle prend en entrée des données relatives au climat, à la plante et au sol.

Les calculs nous permettent d'obtenir en sortie le taux de satisfaction des besoins en eau et les différentes parts du ruissellement, du drainage et du stock résiduel du sol.

Le modèle a été validé par comparaison aux mesures des consommations en eau réelles (ETR) observées sur les sites d'expérimentation de l'ISRA à travers le Sénégal.

II ALIMENTATION EN EAU ET RENDEMENT

La forte variabilité de la pluviométrie joue un rôle déterminant dans la production du mil et sur l'autosuffisance alimentaire.

Les résultats montrent une corrélation faible entre la pluviosité et la production et les rendements.

Par contre les taux de satisfaction des besoins en eau explique 92 % de la variance des rendements.

Le modèle et la prise en compte de la physiologie de la culture et du sol explique mieux les variations des rendements que la seule prise en compte de la pluviosité globale.

Il est utilisé au Sénégal pour informer les autorités sur les conditions de déroulement de la saison.

DEVELOPPEMENT DE LA METHODOLOGIE

Le modèle est basé sur des observations stationnelles et a été validé sur la base des résultats agronomiques.

La prise en compte de la réalité paysanne et de la variabilité spatiale nous a amené à mettre en place un réseau
d'observation des parcelles paysannes et de prendre en compte les méthodes de télédétection.

Le programme coopératif ESPACE est orienté vers la collecte sur le terrain des variables liées au milieu (climat et sol) et Aux techniques culturales. Mené depuis 1980 il a produit ses premiers résultats permettant de tenir compte de la fertilisation dans les relations eau-réndement.

La mauvaise répartition du réseau météorologique nous a fait entreprendre des travaux en matière de télédétection pour restituer à partir de l’IR Meteosat les champs météorologiques de surface et estimer l’ETR à l’échelle régionale à partir des données satellitaires et des observations de surface.

CONCLUSION

La méthode utilisée permet de générer une nouvelle forme de perception du climat et de ses variations. La pluviométrie n’est pas analysée pour elle-même mais mis en regard avec les besoins de l’agriculture.

Cela permet de définir la sévérité et l’extension de la sécheresse et de définir des paramètres d’intérêt agricole tels que les dates d’installation des cultures.

Le passage de l’échelle stationnelle de validité de ces données aux échelles spatiales pose des problèmes de méthodologies qui nous préoccupent en ce moment.
IBSNAT PROJECT

International Benchmark Sites Network for Agrotechnology Transfer
Excerpts from: IBSNAT Brochure 02-E 10/86 1M

Contains material presented by:
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GOAL

The goal of the IBSNAT Project is to provide agricultural development agencies with the means to overcome bottlenecks that currently prevent the timely integration of new or alternative crops, cultivars, products and practices into existing farming systems which would render them more productive, stable, sustainable, and equitable for the resource-poor farmers of the developing world.

PURPOSE

The purpose of the IBSNAT Project is to develop a methodology for the transfer of agroproduction technology that combines elements of transfer by analogy with systems analysis and simulations which results in desired outcomes. By combining soil, crop, weather, and farm management data bases with simulation models and expert systems, IBSNAT is developing a decision support system that allows government agencies to undertake long-term, strategic planning and farmers to make day-to-day tactical decisions. This systems-based approach (Figure 1) emphasizes interdisciplinary teamwork since understanding gained from the physical, biological, social, and economic disciplines is needed for efficient and effective agrotechnology transfer.

OBJECTIVES

The objectives of the IBSNAT Project are to:

1) accelerate the flow of agrotechnology from its site or origin to new locations;
2) maximize the successes and minimize the risk associated with the transfer of agricultural technology; and
3) assess the long-term effects of agricultural practices on the agroecosystem.

IBSNAT aims to achieve these objectives by:

- Establishing a global prototype network to generate information necessary to develop and test a decision support system for agrotechnology transfer.

- Demonstrating the usefulness and applicability of the systems-based approach in developing countries.

- Training scientists in developing countries to utilize this methodology.

- Catalyzing the establishment of regional networks that employ systems-based methods for the transfer of agrotechnology.
WHAT IS DSSAT?

The three essential ingredients of DSSAT and of any decision support system are:
1) decision aides;
2) data bases; and
3) a dialog generator.

Decision aides are either simulation models or expert systems. Simulation models are particularly useful for strategic planning by government planners. With the proper natural resource data base, a planner may simulate the performance of a crop, product, or practice at any location in a country for any season and for a wide range of user options. Simulation models are indispensable, not only because they can provide answers quickly and at very low cost, but also because they can do what no researcher can demonstrate experimentally. Models can simulate processes for 25, 50, or more years. These long-term simulations enable planners to evaluate the impacts of recurring droughts and to prescribe alternative crops, products, or practices to minimize losses.

While simulation models are helpful for strategic planning, expert systems are needed for tactical planning at the farm or intermediary (i.e., extension) level. They can be used to identify and control plant pests, schedule irrigation, fertilizer application, or spraying. Expert systems enable young and inexperienced extension agents to sift through a large knowledge base in a matter of minutes to obtain expert recommendations for specific problems for a specific location and situation. The power of expert systems lies not only in their capacity to capture and mimic the knowledge of scientific experts, but the knowledge of farmers as well. Scientists generate quantitative, mechanistic knowledge that can be expressed mathematically and this has been called algorithmic knowledge. Farmers, on the other hand, employ rules of thumb, educated guesses, intuitive judgments, or what we all know as "plain, common sense." This type of knowledge is what those in the field of artificial intelligence are attempting to replicate and is known as heuristic knowledge.

The successful functioning of decision aides in agrotechnology transfer is dependent, however, on the availability of natural resource data bases containing data on crops, soils, weather, and management practices. These data are collected from experimentalists around the world covering a wide range of soils and climates and are composed of the minimum data set (MDS) determined by IBSNAT scientists to characterize a specific site. These include, among others, data on crop management practices, soil water content, soil physical and chemical characteristics, crop biomass and final yield, daily maximum and minimum temperatures, solar radiation, and precipitation.

The greater the amount of information available to the decision aides, the better will they be able to assist users in making agricultural decisions. For, just as the machinery of the industrial age required energy and fuel to operate, the expert systems of the information age need data to predict outcomes.

The most important function of a dialogue generator is to enable the user to communicate with various components of the decision support system in a "user-friendly" manner. It allows for a preplanned man-machine interaction and includes formal programming languages, languages for interrogating data bases, and innumerable non-formal conversational interchanges, many of which are designed for one specific application.
As a decision support system, DSSAT will be able to assist decision-makers, at both the policy and farm level, to efficiently simulate the effects of alternate farm management practices on crop yields, control and optimize production outcomes at strategic and tactical levels, and evaluate many of the consequences of agrotechnology transferred from existing locations to new locations. However, IBSNAT also recognizes the fact that the adoption rate of new agricultural technologies is poor unless they are considered within the overall socioeconomic context of the farm, and is now in the process of conceptualizing models of whole farm systems (Figure 3).

Communication linkages have been established with many countries for the purpose of exploring their common interests in collaborating with and participating in the IBSNAT prototype network (Figure 4).
Figure 1: IBSM's framework for agrotechnology transfer.
Figure 2. The decision support system integrates soil data, experimental data, crop data, weather data, and existing knowledge about the farming systems to enable collaborators to make decisions about production outcomes.
Figure 3. Conceptual framework for whole-farm models.
Figure 4. Communication linkages have been established with many countries for the purpose of exploring their common interests in collaborating with and participating in the IBSMAl prototype network.
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