PD-AAZ-679

CONVENIO DE DONACION PARA PROYECTO DE INVESTIGACION
"PREPARACION DE DISEÑO DE MODELOS SOCIO-ECONOMICOS Y BIOLOGICOS DE SISTEMAS DE PRODUCCION DE FRIJOLES EN GUATEMALA"
ENTRE
LOS ESTADOS UNIDOS DE AMERICA A TRAVES DE LA AGENCIA INTERNACIONAL PARA EL DESARROLLO (AID)
Y EL
INSTITUTO DE CIENCIAS Y TECNOLOGIA AGRICOLA (ICTA)

LIMITED SCOPE GRANT AGREEMENT FOR THE RESEARCH PROJECT
"BIOLOGICAL AND SOCIO-ECONOMIC MODELLING OF BEAN-BASED FARMING SYSTEMS IN GUATEMALA"
BETWEEN
THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (AID)
AND THE
INSTITUTE OF SCIENCIES AND AGRICULTURAL TECHNOLOGY (ICTA)

520-0000-A-00-9402-00

TITULO DEL PROYECTO/ PROJECT TITLE	2. NUMERO/ PROJECT NUMBER
PREPARACION DE DISEÑO DE MODELOS SOCIO-ECONOMICOS Y BIOLOGICOS DE SISTEMAS DE PRODUCCION DE FRIJOLES EN GUATEMALA	936-5542.21
BIOLOGICAL AND SOCIO-ECONOMIC MODELLING OF BEAN-BASED FARMING SYSTEMS IN GUATEMALA	FISCAL DATA 72-1191021.6 DDSA-89-29520-KG11 (ALLOWANCE 946-51-520-00-19-91)

3. Por este medio las partes arriba mencionadas, de común acuerdo, convienen en llevar a cabo el proyecto descrito en este Convenio de acuerdo con (1) los términos de este contrato incluyendo el ANEXO "A" Descripcion de Proyecto, el ANEXO "B" Presupuesto Ilustrativo, ANEXO "C" la Propuesta Aprobada, ANEXO "D" Disposiciones Generales, y ANEXO "E" Disposiciones Administrativas y Fiscales y (2) cualquier acuerdo general en relación a cooperación técnica o económica. La compra de productos por el donatario deberá estar de acuerdo con el Manual 11 de AID (Divisas) y con el Capítulo 18 del Manual 1 de AID, Suplemento B (Moneda Local), incluidos como ANEXO F y ANEXO G.

The above named parties hereby mutually agree to carry out the project described in this Agreement in accordance with (1) the terms of this Agreement, including ANNEX "A" Project Description, ANNEX "B" Illustrative Budget, ANNEX "C" the Approved Proposal, ANNEX "D" Standard Provisions and ANNEX "E" Adminstrative and Fiscal Provisions hereto, and (2) any general agreement regarding economic or technical cooperation. Procurement of commodities by the Grantee shall be in accordance with AID Handbook 11 (Foreign Exchange) and Chapter 18 of AID Handbook 1, Supplement B (Local Currency), enclosed as ANNEX F and ANNEX G.

4. MONTO DE LA CONTRIBUCION DE AID/ AMOUNT OF AID CONTRIBUTION	5. FECHA DE FINALIZACION DE LA ASISTENCIA DEL PROYECTO (FFAP)/ PROJECT COMPLETION DATE
$150,000	MAYO 15, 1992

6. El propósito de este proyecto es propocionar ayuda para el diseño de un modelo de simulación de sistemas de producción de frijol en fincas de Guatemala e identificar tecnolgía apropriada por medio del uso del modelo para mejorar sistemas de producción de frijol en fincas. El proyecto contribuirá al desarrollo de métodos de investigación y a la extensión de técnicas al beneficio del pequeño y mediano productor agrícola de las áreas rurales de Guatemala. El Instituto de Ciencias y Tecnolgía Agrícola coordinará y ejecutará las actividades que se describen en el Convenio de Donación.

The purpose of this project is to provide assistance to develop a whole farm simulation model for bean-based farming systems in Guatemala and identify appropriate technology for improvement of bean-based farm systems through application of the model. The project will contribute to the development of research methods and extension technologies benefitting the small and medium scale farmers of rural Guatemala. The activities described within this Limited Scope Grant will be coordinated and carried out by the Institute of Science and Agricultural Technology (ICTA).

7. POR EL DONATARIO/ FOR THE GRANTEE	POR LA AGENCIA PARA EL DESARROLLO INTERNACIONAL (AID)/ FOR THE AGENCY FOR INTERNATIONAL DEVELOPMENT
Horacio Juárez A.	Anthony Cauterucci
FIRMA/SIGNATURE	FIRMA/SIGNATURE
TITULO/TITLE	TITULO/TITLE
ICTA DIRECTOR	USAID/Guatemala Director
FECHA/DATE	FECHA/DATE

ANNEX A

PROJECT DESCRIPTION

A. Project Purpose:

This project will develop a whole-farm simulation model for bean-based farming systems in Guatemala and identify appropriate technology for improvement of bean-based farm systems through application of the model.

B. Background:

The Instituto de Ciencia y Tecnologia Agricolas (ICTA) has historically played a lead role in the development of the Farming Systems Approach to agriculture research and extension and in the development of research methodologies. Under the USAID/S&T bean-cowpea CRSP and using a modified FSR approach, ICTA has also been active in developing and transferring new bean varieties to small landholding farmers in Guatemala.

Under the lead of head researcher, Dr. Porfirio Masaya, ICTA developed and presented, in conjunction with the University of Florida and the Edinburgh School of Agriculture, a research proposal for funding under USAID/SCI's Program in Science and Technology Cooperation (PSTC). This proposal, entitled "Biological and Socio-Economic Modelling of Bean-Based Farming Systems in Guatemala", was reviewed by an external panel of scientists and subsequently recommended for funding. The proposed research would develop a whole-farm simulation model to be used in testing the degree of generalization of site-specific research results to other areas where the research results might also be applicable. The project will attempt to demonstrate the advantage of the use of valid simulation models over traditional experimentation, and the ability to assess technological packages across sites and over time.

The project was approved for funding by AID/SCI in Washington and received Mission concurrence on 2/8/89. The three year research project will be funded under appropriation 72-1191021.6, budget plan code DDSA-89-29520-KG11 (allowance 946-51-520-00-19-91) at a maximum level of $150,000.

C. Project Activities:

The research project's activities involve the collection and analysis of crop-based and socio-economic field data contributing to the development of a whole-farm simulation model of a bean-based farming system. The crops, soils and weather data bases will be used to develop and validate the crop simulation models, while the socio-economic data base will be used to formulate a region specific whole-farm simulation model. The computer model

will be designed to run on PC microcomputers. A workshop will be held at the end of the research activity to demonstrate the use of the model for local scientists. A copy of the approved proposal, enclosed herewith as ANNEX C, is provided for reference and clarification for any question pertaining to any specific research activity, should the need arise.

Specific research components include the following:

1. Building a soils and weather data base: This activity includes the collection of historic rainfall and temperature data for the Jutiapa region, measurement of solar radiation at four locations within the same region, and testing of the weather generator model currently being used in the Decision Support System for Agrotechnology Transfer to determine its applicability for the Jutiapa region.

The soils data base will include soil characteristics of each farm, and in areas of highly variable soils, of each field. The data base will be defined on the basis of the newly collected soil profile characterizations, existing soils maps, soil characterization tables, and data from the international soils data base.

2. Collecting crop growth information: Data on vegetative and reproductive growth phases of beans, corn and sorghum grown under distinct monoculture and intercrop systems will be collected through a series of replicated, experiment-station based and on-farm field trials. Final yield data for both monoculture and intercropped plots will be collected for a large sample area to measure the interaction effects of the crops grown together. Data will be analyzed statistically and will be used to define intercropping effects in the dry bean, corn, and sorghum growth models.

3. Validating the crop growth models for beans, corn, and sorghum with data collected from the Jutiapa region: After crop models have been calibrated and parameters have been defined for the various cultivars and land races under study, model predictions need to be verified and validated for the Jutiapa region. If model predictions are consistently biased, model adjustment will be made.

Model modifications will also be made to account for the intercropping of beans with corn, beans with sorghum, and a mixture of beans, sorghum, and corn. Similar modifications will also be made in the CERES-sorghum and Ceres-Maize model to account for the competition between corn and bears and sorghum and beans.

4. Construction of a socio-economic data base characterizing the Jutiapa region: Farm-level data will be

collected on labor utilization and availability, farm size and structure, prices of input and products, household and discretionary consumption patterns, capital and credit availability and patterns of investment and disinvestment, household objectives and attitudes, and farm management and environmental characteristics. The data base will contribute to the development of a whole-farm simulation model and will be used in conjunction with the crop simulation models.

5. Building a whole-farm simulation model and validating it for the Jutiapa region: Once individual crop and whole farm models have been developed and validated, they will be integrated and run together. The results of the simulations will be compared with sets of constraints defined from the socio-economic data base to test whether selected management options are feasible within the environment of the resource-poor farmer. Various factors, including period of maturation, planting date, cultivar type, irrigation and other management alternatives will be tested against a range of socio-economic constraints within the whole-farm model.

6. Workshop: A workshop will be held at the start of year three to demonstrate the use of simulation models to interested groups of potential end-users of information generated by the crop and whole-farm models. The workshop will emphasize the principal advantage of the use of valid simulation models over traditional experimentation, and the ability to assess technological packages across sites and over time.

D. Reporting Requirements:

Interim progress reports are required every six months except for the last six month period which will be pre-empted by a final project report. Since research schedules often are not updated until after funds are obligated, the first report should include any revisions in key dates of the research schedule. Substantive scientific input should be included when there is something to report. Six copies of the interim reports should be submitted to the Chief/ORD in USAID/Guatemala, or his designated representative, no later than 30 days following each six month period. Interim reports may be in Spanish if an English summary accompanies the report.

Six copies in English of the final report should be submitted by the principal investigator to the Chief/ORD, or his designated representative, no later than six months after the completion date of the project. The final report should be sufficiently detailed to substantiate findings and to permit scientific evaluation of research. It will contain copies of any computer

models developed, in easily computer-readable format (i.e., 5 1/4" or 3 1/2" PC compatible-format computer discs) and copies of all operating manuals and tutorials in both English and Spanish.

E. Evaluation:

Project evaluation will be based on analysis of final report and other information deemed appropriate by project manager. The final evaluation will be completed within 90 days of the final report submission and should contribute to Mission's project completion report.

F. Project Management and Timetable:

ICTA will assign as lead investigator, Dr. Porfirio Masaya, to provide overall direction and management of the research project. The various roles and responsibilities of the three institutions involved in the project, as defined on pages 28-29, section 5.5.2, "Responsibilities", in the approved copy of the submitted proposal, are the following:

--Crop data will be collected by ICTA; data collection procedures will be reviewed with University of Florida crop modelers to guarantee that all necessary information with respect to crop growth and development will be tollected.

--The socio-economic data will be collected by ICTA and an anthropologist hired through the project. Data collection procedures and surveys will be thoroughly discussed with the FSR modelers from the Edinburgh School of Agriculture.

--Calibration and validation of the biological models will be the responsibility of the crop modelers at the University of Florida. It is expected that throughout the project ICTA agronomists and breeders will be involved and that they will be taught how to work with and modify the models.

--Crop model experimentation will be a collaborative effort between ICTA agronomists and breeders and the University of Florida crop modelers.

--Whole farm model synthesis will be the responsibility of the FSR modelers from the Edinburgh School of Agriculture, in close cooperation with the socio-economists at ICTA.

--Whole farm model experimentation will be a collaborative effort between the ICTA socio-economists and the FSR modelers.

--The workshop will be the responsibility of all people involved in this project.

--Field work design and implementation will be the responsibility of the ICTA research team, in close cooperation with the FSR modelers from the University of Edinburgh and the crop modelers from the University of Florida.

The time schedule of research activities is presented below:

Time schedule

```
                                Year        1          2          3
                                     |-0-0-0-0-0-|-0-0-0-0-0-|-0-0-0-0-0-|

data collection                      ----------------------
 - crop                              ----------------------------
 - socio-economic

biological model
 calibration and validation                 -------------------

biological model experimentation                     -----------------

whole farm model synthesis                 -------------------------

whole farm model experimentation                                 -----------

implementation
 - workshop                                                          |
 - field work design                                              ------
```

Total combined budget for ICTA, Guatemala, and the University of Florida.

	US $ year		
	1	2	3
Personnel			
Anthropologist	7,000.00	7,000.00	0.00
Technicians	6,000.00	6,000.00	2,000.00
Student assistants	2,700.00	2,700.00	0.00
Student labor	3,000.00	3,000.00	1,197.08
Data processor 0.70 FTE [1]	0.00	0.00	0.00
Agronomist 0.40 FTE [1]	0.00	0.00	0.00
Socio-economist 0.30 FTE [1]	0.00	0.00	0.00
Plant breeder 0.25 FTE [1]	0.00	0.00	0.00
Bio-economist 0.40 FTE [2]	0.00	0.00	0.00
Crop modeler 0.25 FTE [3]	0.00	0.00	0.00
Agric. Systems modeler 0.05 FTE [3]	0.00	0.00	0.00
FSR Specialist 0.05 FTE [2]	0.00	0.00	0.00
Equipment			
Microcomputer	5,000.00	0.00	0.00
Leaf area meter	6,600.00	0.00	0.00
Minimum weather stations (3)	5,100.00	0.00	0.00
Oven and plant sample drier	2,500.00	0.00	0.00
Digital balance	1,000.00	0.00	0.00
Backpack motor sprayer (2)	1,500.00	0.00	0.00
Camera	500.00	0.00	0.00
Seed moisture meter	600.00	0.00	0.00
File Cabinets (2)	300.00	0.00	0.00
Desks (2)	300.00	0.00	0.00
Computer desk	250.00	0.00	0.00
Book Shelf	100.00	0.00	0.00

[1] Supported through collaboration with ICTA-Guatemala.

[2] Supported through collaboration with the University of Edinburgh.

[3] Supported through collaboration with the University of Florida.

Transportation			
Vehicles or trucks (2)	20,000.00	0.00	0.00
Gasoline and diesel	2,000.00	2,000.00	1,000.00
Maintenance	1,800.00	1,800.00	900.00
Materials and Supplies			
Materials	4,500.00	3,500.00	1,450.00
Xerox, telephone, telex, stamps	750.00	750.00	400.00
Training			
Workshop	0.00	0.00	5,000.00
Travel			
US-Guatemala	10,000.00	8,000.00	4,000.00
Domestic	2,800.00	2,800.00	1,400.00
International	500.00	2,000.00	1,500.00
	------.--	------.--	------.--
Sub total	84,800.00	39,550.00	18,847.08
Other Expenses			
Indirect Costs (UF)	3,029.00	2,563.00	1,210.92
	------.--	------.--	------.--
Total	87,829.00	42,113.00	20,058.00
Grand Total			150,000.00

Budget for ICTA, Guatemala (US $).

	year		
	1	2	3
Personnel			
Anthropologist	7,000.00	7,000.00	0.00 (1)
Technicians	6,000.00	6,000.00	2,000.00 (2)
Student assistants	2,700.00	2,700.00	0.00 (3)
Data processor 0.70 FTE	0.00	0.00	0.00
Agronomist 0.40 FTE	0.00	0.00	0.00
Socio-economist 0.30 FTE	0.00	0.00	0.00
Plant breeder 0.25 FTE	0.00	0.00	0.00
Equipment			
Microcomputer	5,000.00	0.00	0.00 (4)
Leaf area meter	6,600.00	0.00	0.00 (5)
Minimum weather stations (3)	5,100.00	0.00	0.00 (6)
Oven and plant sample drier	2,500.00	0.00	0.00 (7)
Digital balance	1,000.00	0.00	0.00 (8)
Backpack motor sprayer (2)	1,500.00	0.00	0.00 (9)
Camera	500.00	0.00	0.00 (10)
Seed moisture meter	600.00	0.00	0.00 (11)
File Cabinets (2)	300.00	0.00	0.00 (12)
Desks (2)	300.00	0.00	0.00 (13)
Computer desk	250.00	0.00	0.00 (14)
Book Shelf	100.00	0.00	0.00 (15)
Transportation			
Vehicles or trucks (2)	20,000.00	0.00	0.00 (16)
Gasoline and diesel	2,000.00	2,000.00	1,000.00 (17)
Maintenance	1,800.00	1,800.00	900.00 (18)
Materials and Supplies			
Materials	4,500.00	3,500.00	1,450.00 (19)
Xerox, telephone, telex, stamps	750.00	750.00	400.00 (20)
Training			
Workshop	0.00	0.00	5,000.00 (21)
Travel			
Domestic	2,800.00	2,800.00	1,400.00 (22)
International	500.00	2,000.00	1,500.00 (23)
	------.--	------.--	------.--
Total	71,800.00	28,550.00	13,650.00
Grand Total			114,000.00

Budget for the University of Florida (US $) [4].

	year		
	1	2	3
Personnel			
Student labor (OPS)	3,000.00	3,000.00	1,197.08 (24)
Crop modeler 0.25 FTE	0.00	0.00	0.00
Agric. Systems modeler 0.05 FTE	0.00	0.00	0.00
Travel			
US-Guatemaia	10,000.00	8,000.00	4,000.00 (25)
Sub total	13,000.00	11,000.00	5,197.08
Other Expenses			
Indirect Costs (23.3 %)	3,029.00	2,563.00	1,210.92
Total	16,029.00	13,563.00	6,408.00
Grand Total			36,000.00

Budget justification.

1. An anthropologist will collect the socio-economic data described in the data collection procedures. The person will be supervised by the socio-economist (Carlos Heer) and will cooperate closely with ICTA and DIGESA people stationed in Jutiapa.

2. Technicians will help with the collection of growth analysis data for dry bean, corn, and sorghum field studies. Especially the separation of the plants into different components is very labor intensive.

3. A total of six undergraduate students will be involved for their undergraduate thesis projects as part of their study for a Ingenieer Agronomo (B.Sc) degree. Each person will be responsible for one growth analysis experiment with either beans, corn, or sorghum, and will receive a small compensation for his work. The undergraduate students will be supervised by Dr. Masaya, and Ing. Monterroso. .

[4] Travel by the bio-economist will be reimbursed through the University of Florida.

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4. Currently no microcomputer is located at the experiment station in Jutiapa. A complete IBM-AT compatible machine with a 82287 processor will be purchased, including a harddisk, math-coprocessor, color monitor, battery powered back-up power supply, printer, modem, and the necessary software. The microcomputer will be used to enter the socio-economic data, create a data base, and run the crop and whole farm model.

5. The leaf area meter will be used to measure the leaf area of plant samples collected during the growth analysis studies. Any existing procedures, e.g. measuring length and width of each leaf, tracing the leaves and weighing the paper, or xeroxing the leaves are extremely labor intensive and very inaccurate. Leaf area is an important state variable predicted by the model and needs to be validated with accurately measured leaf area samples.

6. Currently the existing INSIVUMEH weather stations in the Jutiapa area collect only maximum and minimum air temperature and rainfall, which are recorded manually. Climatic data required for the models include radiation, air temperature, and rainfall. The LICOR-1200S minimum weather stations will record all data necessary for the models automatically and will store up to 200 days of data. The minimum weather stations will be placed at the current locations where rainfall and temperature are being recorded, e.g. Quezada, Asuncion Mita, and Agua Blanca.

7. There is no plant sample drier at the Jutiapa experiment station. The oven currently being used is on loan from another location and will need to be returned at the end of this season. The plant sample drier will be used to dry all the plant samples collected in the growth analysis studies for dry weight determination. Dry weights of leaves, stems, petioles, seeds, and pods are important state variables predicted by the crop models as a function of time and will need to be validated.

8. A digital balance is needed to weigh the dried plant samples and determine dry weight of leaves, stems, petioles, seeds, and pods. (see 7 for further justification).

9. Two backpack motor sprayers will be used to spray the crop model calibration plots at the Jutiapa experiment station and the plots in the farmers' fields with fungicides and pesticides to prevent unnecessary losses due to pests or diseases.

10. The camera will be used to make pictures or slides of the various plots and plants during the regular growing season. Plant observations will be recorded on film in order to be able to verify the actual status of a particular treatment later when the data are being used for model calibration and validation.

11. A seed moisture meter will determine percentage moisture content of the seeds at final harvest; it is an indication of the harvest maturity of the seeds.

12. File cabinets will be used to store records and data collected during the field and socio-economic studies.

13. A desk is needed for the anthropologist, hired by this project, and the agronomist, paid by ICTA.

14. A computer desk is needed for the computer and printer. A special room with an air conditioner will be assigned for computer use at the experiment station in Jutiapa. The ICTA supported data processor, Ms. V. Ibañez, will be entering the data, supervised by Ing. Carlos Heer.

15. The book shelf will be used to store software, manuals and other related computer books and magazines.

16. Transportation is a very high priority item in this project. Because data will be collected over a relative large area, vehicles are needed for the researchers to be able to visit the farmers for surveys or visit the experiments in the farmer's fields. Data collection will be very intensive and therefore one vehicle needs to be assigned permanently to the project supported anthropologist, responsible for collecting the socio-economic data, and one vehicle will be assigned to the ICTA agronomist, Ing. Monterroso, responsible for plant data collection. Because of the poor condition of the paved roads in Guatemala, and the many unpaved roads to small towns or villages, the actual life span of vehicles is not as long as in the US.

17. Gasoline and diesel for the two trucks mentioned in item 16, and for the trucks used by the ICTA breeder, Dr. Masaya. and ICTA socio-economist, Ing. Heer, involved in the project.

18. Maintenance of the new vehicles and for the trucks used by the ICTA breeder, Dr. Masaya, and the ICTA socio-economist, Ing. Heer, involved in the project. Because of the conditions of the roads, more maintenance is required (see 16).

19. Materials include seed, fertilizer, herbicides, pesticides, fungicides, tags, sample bags, and others for conducting the experiments. It is also includes office supplies: paper, pens, etc., and computer supplies: diskettes, and computer paper.

20. Line item allocated for xerox copies, stamps for postage, telephone and telex expenses.

21. One of the objectives of the project is to organize a workshop to demonstrate the models to potential users. Costs will include the rental of microcomputers, printing of handout material, mailing and telephone expenses, and the reimbursements of some participants for room and board if their organization can not support them. It is planned to hold the workshop during the beginning of the third year, which will be in the fall of 1991. The workshop will last between three to five days.

22. Domestic travel expenses will be used to reimburse Dr. Masaya, Ing. Heer, and Ing. Monterroso, and the project supported anthropologist for travel directly related to socio-economic or plant data collection. It is expected that some overnight travel will need to be done by some of the project investigators. Jutiapa is not within

commuting distance of Guatemala City (three hour drive). Dates can not be predetermined because of the uncertainty of the timing of some of the experiments.

23. International travel will mainly be used by the Guatemalan investigators, Dr. Masaya, Ing. Heer, and Ing. Monterroso, to attend the annual meeting of the PCCMCA (Central American Agricultural Organization) to present oral and poster presentations of the results of this study. The PCCMCA is organized once a year during late March or early April in a Central American city.

24. A part-time University of Florida student will receive the crop data collected in the field experiments in Jutiapa, check for errors, and enter the data into the existing Database Management System of DSSAT. After data entry the student will create the input files for the crop models through the data retrieval program, and will do a first calibration or validation of the crop models. The student will also run the weather generator and strategy analysis programs. The student will be supervised by the University of Florida supported crop modelers, Dr. Hoogenboom and Dr. Jones.

25. The major part of the Florida budget is spent for travel between the United States and Guatemala by the University of Florida supported crop modeler, Dr. Hoogenboom, and the University of Edinburgh supported bio-economist, Dr. Thornton, to assist and advise with the data collection procedures. It is also planned that part of the time will be spent with the cooperators on teaching them how to use the already existing software (crop models, DSSAT), and the still to be developed whole-farm model. Several trips will need to made during the length of the project because of the many experiments designed for data collection and the development of the various models. An average trip will probably last between 10 to 14 days and will cost around $ 2,000.00. Five trips are scheduled for the first year (three for the bio-economist, two for the crop modeler), four for the second year (two trips each for the bioeconomist and the crop modeler), and travel for the last year includes the expenses of the bio-economist Dr. Thornton and the crop modeler Dr. Hoogenboom to organize and participate in the workshop.

ANNEX C

APPROVED PROJECT RESEARCH PROPOSAL

9.245

Program in Science and Technology Cooperation (PSTC)

BIOLOGICAL AND SOCIO-ECONOMIC MODELLING OF BEAN-BASED FARMING SYSTEMS IN GUATEMALA

Submitted by

Instituto de Ciencia y Tecnologia Agricolas, Guatemala

in cooperation with

University of Florida, Gainesville, Florida

Project ID Number 9.245

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NAME : Date
TITLE:
ADDRESS:
TEL:

NAME : Date
TITLE:
ADDRESS:
TEL:

NAME : J. B. Dent Date 16/8/88
TITLE: Professor
ADDRESS: Edinburgh School of Agriculture
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TEL: 031-667-1041

NAME : P. K. Thornton Date 16/8/88
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Rec'd in SCI AUG 24 1988

Proposed starting date: April 1989
Duration: 3 years
Total Cost: US $150,000

University of Florida
Authorized Representative:

Dillard C. Marshall, Assistant Director of Research
Division of Sponsored Programs

Program in Science and Technology Cooperation (PSTC)

Full Proposal

BIOLOGICAL AND SOCIO-ECONOMIC MODELLING OF BEAN-BASED FARMING SYSTEMS IN GUATEMALA

Submitted by

Instituto de Ciencia y Tecnologia Agricolas, Guatemala

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University of Florida, Gainesville, Florida

Project ID Number 9.245

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Duration:	3 years
Total Cost:	US $150,000

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1. OVERALL AIM AND SPECIFIC OBJECTIVES

The project constitutes a case study to prove the hypothesis that computer simulation models can play a significant role in enhancing the efficiency of both agricultural field experimentation and the identification of promising agrotechnologies in lesser developed countries. It is proposed to adapt and validate existing crop simulation models for bean, corn and sorghum for the region of Jutiapa in southeastern Guatemala. These crop models will then be embedded in a whole farm simulation model that represents in a mechanistic manner the major biological, social and economic aspects of smallholder farmers. This integrated computer model will be used as follows:

- to develop a methodology for identifying efficiently the most promising genetic types that will produce a high and stable yield under the environmental conditions in Jutiapa, thereby reducing the number of field plots required and decreasing the time between first selection by the breeder and release to farmer;
- to investigate the biological and socio-economic effects of early-maturing bean varieties in typical smallholder production agroecosystems in Jutiapa; and
- to identify ways of increasing production and household income through the screening of many agricultural production alternatives for resource-poor farmers that fit in with their objectives and goals.

Specific objectives for Jutiapa, Guatemala, are as follows:

(1) to build a data base for soil and weather variables of this bean producing area.
(2) to validate the crop simulation models for dry bean, corn, and sorghum.
(3) to predict the production of current bean land races and improved dry bean varieties in monoculture and in combined cropping systems with corn and sorghum in farmers' fields.
(4) to build a data base for socio-economic variables that describe the production frame of smallholder farms.
(5) to construct a whole farm simulation model and identify appropriate technology packages through application of the model.

2. RELEVANCE TO DEVELOPMENT

Experience over the last thirty years has shown that it is difficult to develop appropriate crop technologies and transfer them successfully to farmers engaged in what is essentially subsistence agriculture. In many countries field experimentation, either in outlying research stations or in farmers' fields, is often the basis of this development through identifying suitable technology (research) and demonstrating its usefulness (extension). The results of experiments are normally heavily dependent on the climate sequence in the particular season in which they are carried out, the specific soil type on which the experiment takes place, and numerous management factors under the control of the researcher. The critical issue is the following: whether the technology packages based on these results will operate in a similar fashion in the fields of resource-poor farmers in a different place, in a different year, on a different soil type, and where farming operations

are constrained by socio-economic factors neither experienced nor perceived at the research station where field experiments are often carried out.

Agricultural research in Jutiapa that studies the different crop production options is advanced in comparison with the techniques used by farmers (ICTA, 1984). At some point this research needs to be integrated with extension. For the extension service and other developing agencies of the government it is crucial to understand the consequences of the innovations, or other changes in the production of subsistence crops in a region. This project aims to increase the efficiency of the transfer of technology, both in the design of appropriate packages for small farmers and in the extension of the results. It is proposed to integrate biological crop simulation models with the most important attitudinal, social and economic factors that constrain, or otherwise impinge upon, agricultural production in a particular place. This application of systems methodology can be expected to complement more traditional agricultural research, not to replace it. Simulation modeling can thus be seen as a tool within the conceptual framework of Farming Systems Research (FSR), extending the applicability of traditional field experimentation in the technology design and assessment phases of FSR (Dent and Thornton, 1988 {see Appendix}).

The results anticipated from this project have implications for speeding the technology transfer process wherever the biology and the socio-economics of smallholder systems can be adequately quantified. Moreover, it should prove possible to aggregate farmer response over a region to give those involved in policy making an objective basis on which to make decisions (Ministerio de Agricultura, 1986). The focus will be on farming systems that include beans, a relevant type of system in Central America and the Caribbean (De Leon et al., 1977). The use of models that predict the performance of bean producing practices is a methodology which, once it has proved successful in Jutiapa, can be used in other regions in Guatemala, the Central American region, or other areas of the world. They can also be instrumental in the acceleration of adoption and dissemination of research results, from Guatemalan and Central American agencies and research institutions (Viana and Borbon, 1988). The implications for the U.S. Agency for International Development (AID) of a successful case study in the application of these computer models are profound: a methodology that can be demonstrated to work and is repeatable in other locations, that provides an enhancement to costly and time-consuming agricultural experimentation, that helps to avoid duplication of effort, and that enhances the efficiency of development, through identification, testing and dissemination of more appropriate technology for resource-poor farmers in the tropics.

Two features of this simulation methodology stand out: *repeatability* across space, and *repeatability* over time. The first is the embodiment of technology transfer: being able in an objective fashion to assess crop performance in locations where field experiments have not necessarily been carried out. The second provides the means for studying the dynamics of agricultural production systems, this flux brought about by the changing circumstances of production or through the operation of stochastic elements. The proposed research seeks to demonstrate how these features can be harnessed for the benefit of agricultural research in lesser developed countries.

3. INNOVATIVE ASPECTS

3.1 Environment

The Instituto de Ciencia y Tecnología Agrícolas (ICTA) has been active in developing and transferring new bean varieties to small landholding farmers in Guatemala (Davila and Orozco, 1980; Pachico et al., 1987; Ruano, 1984). The development of new disease resistant and high yielding varieties has been followed by an active scheme of technology promotion. These conditions provide an unique example in which to study the changes in production practices by farmers in contrasting soil conditions, and with different technologies (Masaya et al., 1988a,b). The current effort in ICTA is the development of bean varieties suited to farms where the rainfall patterns are crucial for producing bean crops and where the soils change not only according to classification but also by the differences between hillside and flat land farming (Masaya, 1988b).

3.2. A New Methodology

The biological models sponsored by International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) are the first series of crop models that can be described as being portable between environments while at the same time being robust and having realistic data requirements for operation. These models allow the simulation of crop growth and development on a day-to-day basis, in response to climate, soil conditions, genotype, and many types of management inputs.

This project seeks to develop and apply new methodologies at two levels. The first involves the use of the biological simulation models in the research process, specifically as tools to aid in screening genotypes in different simulated environments and years. The second level involves the construction of a whole farm model. The linkages between detailed biological simulation models and the socio-economic environment of farming in the tropics, as envisioned in the current project, have not previously been forged. It is proposed to build these links to produce a simulation model of the family farm that is highly flexible, mechanistic, and capable of reacting in a meaningful way to changes in farm characteristics.

3.3. Technology Generation

An unlimited number of theoretical experiments or simulations is possible by changing both the initial and input conditions for the crop models. Such conditions involve any combination of soil type, cultivar, planting date, seedling density, and fertilization and irrigation schedules. Any particular combination can then be subjected to a large number of simulated weather sequences to produce probability distributions of yields and other important outputs. Not only can single seasons be simulated in this way, but also sequences of years together can be investigated, where the soil residues of one crop become the inputs for the next, after due allowance has been made for any fallow period. The outputs might

be described in terms of yield or net revenue, for example, and analysis of the experiment then involves the comparison of these probability distributions to identify particularly promising input combinations for the given conditions.

Because of the nature of computer experimentation, it becomes possible to investigate a great diversity of agricultural production alternatives. They may be over long periods of time, involving hitherto untested crops or cropping sequences in the study area. The project is concerned with the identification of new or different production alternatives that are biologically, economically and socially feasible, and that fit in with household objectives, which can then be tested in farmers' fields. Primarily, these alternatives involve the incorporation of new genetic material into the existing production systems in Jutiapa. At the same time this technology could be used to study the introduction of new materials to other locations, for instance the Highlands, which has not been possible in the past because of lack of resources in ICTA.

4. BACKGROUND AND RATIONALE

4.1. The General Problem

The translation of research findings into technology packages that can be widely adopted by farmers constitutes a major problem in the development of agriculture in many countries. There are a number of reasons for the delay between the identification and adoption of technology, but most of these stem from an incomplete understanding of the biological, social, economic and political environment within which resource-poor farmers practice agriculture. Farming Systems Research was developed in an attempt to reduce this delay and to encourage farmers to introduce new technologies more quickly (Biggs, 1985).

The following phases of Farming Systems Research can be identified: *diagnosis*, where existing production systems are examined with respect to constraints of all kinds; *design*, where potential improvements are identified; *testing*, where promising production possibilities are evaluated under local farmers' conditions; and *extension* and *monitoring*, where these promising production alternatives or packages are passed on to more farmers and evaluated further.

Generally, assessment of experimental findings leads to the testing of a preliminary technology package on a small number of farms in a region. The package might involve a particular cultivar selection, fertilizer application, and disease or pest control program. The results from small scale plots are monitored, usually over a number of seasons, and the appropriateness of the package may be confirmed. If so, the package may then be applied on a larger scale on a limited number of farms, not only with the anticipation of again confirming the value of the package, but also now collating farmers' initial reactions and their views on management problems. Eventually, the package may be established at full scale on a number of reference farms in the region. Monitoring of the crop and of farmers' reactions takes place. Inevitably, several more seasons must be involved. A similar procedure could be anticipated for other crop and livestock enterprises before the farming

systems researcher can be expected finally to put together a suitable crop rotation and assess yields, their variation, and thus expected profitability of a whole farming system package.

The advantage of this approach is that the technology is assessed in a whole farm context; interactions between the various farm activities during the whole course of the year are included in the assessment process. A full appreciation of the resource demands of the farm is possible, and the managerial and social implications for farmers and their families may be judged. It is clear, however, that time and substantial resources are involved, and that, in addition, no assessment can readily be made of how the package should be modified in different districts in response to different soils and changing local climates. A further problem with FSR as it is commonly applied is that the dynamic element of farming systems is often not treated explicitly. In particular, socio-economic conditions can change rapidly, making one year's recommendations inappropriate for the following year (Maxwell, 1986).

4.2. The Role of Modeling

The introduction of systems methodology and simulation models into the FSR process has some potential for helping to overcome the problems cited above. In this discussion of the role of modeling within FSR, the starting point is the following consideration: the procedure is well understood whereby with a suitable crop model, growth, development and yield can be simulated in any properly and fully described environment: that is, in any climate, on any soil type, with any managerially controlled input, and for any cultivar of the crop type involved.

It has been demonstrated that these crop models can be validated for widely differing areas of the world; in other words these models are portable and robust, and that diverse environments and conditions can be successfully simulated in response to changes in data input (Boote et al., 1986; Hoogenboom et al., 1988b). The development of detailed biological simulation models with the characteristics of portability, robustness, common data input and output formats, and highly useful levels of sensitivity to soil, weather and management factors, itself a new departure, has important implications for agricultural research in developing countries. Such models can be used in a number of ways. The basic tenet is the following: once validation has been performed for any locality, by comparing simulated crop performance with field trial results using identical weather, soil and management inputs, it becomes possible to use the models to predict crop response under conditions for which the researcher has no real-life data with which to compare model output. Furthermore, using stochastic procedures to generate daily weather sequences that have similar statistical properties to historical time series, it becomes possible to run the crop models over many seasons of simulated time, to generate output distributions that can then be used to assess the long-term variability of particular combinations of inputs (for instance, different cultivars planted at different times with different applications of fertilizer).

Farmers, however, operate in an environment limited not only by physical factors,

such as weather and soil type, but also by social, economic and political constraints. Hence, whether a particular technology package is feasible, let alone desirable, might be dependent on whether the farmer has access to credit to buy the necessary fertilizer, or whether he can hire labor to cope with the increased peak demands of the new package, for example. To be able to screen technology packages for small farmers, therefore, it is necessary to take account of such factors, in fact to describe the essential operating environment of the farmer by taking account of the biological, physical, social, anthropological, economic and political factors that impinge. This can be done through embedding crop simulation models in a whole farm simulation model.

The essential hypothesis of the project is this: that any technology package designed and assessed using a whole farm model that takes account of the important factors in a production system is more likely to be appropriate to local farmers, and more likely to be adopted. There are a number of advantages to using a whole farm model:

- a much wider variety of production possibilities can be screened than is possible with field trials;
- all production alternatives can be screened with direct reference to the resource base of the farmer, his objectives, and his attitudes towards risk and uncertainty; and
- production alternatives can be screened over many seasons, using simulated weather sequences; production stability over time can thus be investigated explicitly.

The potential role of such models in research and extension is clear. A further level of use exists, in aggregating the simulated responses of representative farms in an area, to provide information for regional and national policy makers. Given sufficient resources and time, a whole farm model could thus be expected to attack problems at a variety of levels. In order of increasing aggregation and/or complexity, the following levels might be distinguished (with an example of a pertinent problem):

i. technological (which of two cultivars performs better at an experimental site);
ii. whole-farm related (investigating the effects on the production system of a particular technology);
iii. multiple cropping-sequence-related (crop rotation design and yield stabilities);
iv. land capability studies (regional medium- or long-term yield levels and their variation); and
v. socio-economic (the regional effects of substantial changes to farmers' economic or social environment).

It may be noted that the major end-user of the information generated depends on the stage involved: researchers and extensionists deal primarily with problems at the first three levels, the solutions to which are ultimately passed on to the small farmer, while the more aggregated information resulting from the last two levels should be of use to policy makers. It is envisaged that the three years' work proposed here will progress to at least level three.

4.3. Farm Modeling

Modeling has been used for some time in agricultural research in the tropics. According to Anderson et al. (1985) approaches to socio-economic modeling can be divided into optimising and non-optimising, and the latter group into two, descriptive and search-orientated models. It is apparent from this classification that the divisions are permeable rather than rigorous. The non-optimising, descriptive class contains budgeting models, and certain types of econometric models. Budgeting models are conceptually simple but powerful, involving some kind of summarization of the physical and financial features of the farming system. Anderson and Hardaker (1979) note that the major limitation of this type of model rests with the analyst; to this can be added the problem of extrapolation, in an objective sense, of untried technology.

Descriptive econometric models (Rosenzweig, 1984) seek to summarize major relationships in an existing farming system, often through the use of regression techniques on cross-sectional data. With such an empirical approach, it is essentially unknown how to extrapolate the results, either between different situations or as circumstances change in the same location. The optimizing category contains mathematical programming models, Monte Carlo programming models and certain types of econometric models. Mathematical programming models have been used widely (Flinn et al., 1980; Rodriguez and Anderson, 1988), but there are a number of problems with such constrained optimizing methods, notably the appropriateness of the underlying assumptions and the inflexible framework that such methods impose.

Much effort has been expended on econometric models that seek to derive the conditions for the maximization of household utility (Barnum and Squire, 1979; Singh et al., 1986). Again, these are often based on cross-sectional farm data, and suffer from an inability to be used for extrapolation purposes, due to the empirical (rather than the mechanistic or explanatory) relationships used. Simulation models fall in the non-optimising category, and are often descriptive in nature (Konandreas et al., 1983; Thornton, 1988), although they can be used to identify near-optimal regions for whatever objective function is required (Crawford and Milligan, 1982; Beck and Dent, 1987). Historically, the disadvantages associated with simulation models were related principally to the data requirements and the need for truly multi- and inter-disciplinary research teams. The principal advantage was the total flexibility of the model framework.

It is pertinent to observe that no simulation studies to date have had the presence of detailed, robust and transportable biological components; the combining of such crop models with a whole farm framework such as that of Beck and Dent (1987) that takes account of consumption behavior, attitudes to risk, borrowing and investment, extended to incorporate factors in the socio-economic environment peculiar to the relevant small farmers (for instance, infrastructural factors such as the availability of seasonal credit facilities or marketing organizations), thus represents a new departure. In this way, model data requirements are rendered manageable, since the biological components have to be calibrated and validated, rather than built; the issue of extrapolation is addressed explicitly by the input data requirements of the biological models, rendering them transportable over time and space, and by the explanatory relationships used; and flexibility is preserved, since

the models can be used to describe, predict or optimize the pertinent objective function, whatever it may be (Dent and Thornton, 1988).

4.4. Study Location: Jutiapa, Guatemala

A start thus needs to be made in the application of crop models to answer important practical problems in small-farmer agriculture in the tropics. It is proposed to construct whole farm simulation models for typical smallholder production agroecosystems in the department of Jutiapa, Guatemala, to screen alternative technology packages and to explore the effects on household income of a variety of regional development plans to identify appropriate packages for resource-poor farmers that fit in with their objectives and goals.

It is likely that significant improvement in the nutrition of rural and urban Guatemalans could come about by increasing the proportion of beans in the standard maize-bean diet. This is typically of the order of 90% maize and 10% beans. It is estimated by the Instituto de Nutricion de Centro America y Panamá (INCAP) that an amendment of this ratio to 70% and 30% maize and beans respectively, for example, would lead to a significant improvement in many people's diet. Such increases could come about only through increased bean production and/or lower prices.

In the southeast there are 700,000 rural family farms with an average area of two ha., producing 12, 39, and 37 % of national corn, bean and sorghum production, respectively. Moreover, this production accounts for most of the typical rural family income and food source. Ideally, new production options should increase the productivity of most farms in the region, thereby improving the dependability of the source of food and providing some surplus production for sale. It is also important, however, that the agricultural system is sustainable, meaning no environmental damage or depletion of natural resources.

One of the most difficult problems in Central America and also in the Jutiapa area, is the extreme variability of soil quality and climatic conditions, especially rainfall. Although the region is one of the most important bean producing areas in the country, levels of agricultural input remain low. Yield levels of the important crops has increased very slowly over the last few years and is very dependent on climate. ICTA has been involved in studying the production problems facing small farmers in the area since the early 1970's (Hildebrand, 1979a). It has a long tradition in FSR, in search for a better understanding of the reasons behind farmers' adoption, or otherwise, of agricultural production alternatives (Hildebrand, 1976a; 1979b). Because the transferability of research from experiment stations to farmer is small, an on-farm scheme of agricultural research has been developed. ICTA thus has a large network of cooperating farmers which has provided a significant amount of base material with regards to the prevalent production systems. This on-farm research, however, requires resources in personnel and facilities, which both are limiting.

A number of areas has been identified that would benefit from investigations using the whole farm model:

- how to identify the most promising genetic types in an efficient fashion, to reduce the number for testing in plots to manageable proportions;
- on what basis should farmers and their fields be chosen for on-farm testing purposes;
- are the options being investigated feasible within the set of constraints experienced by the target group of farmers ?
- what effects will changes in cultivar type have on smallholder bean production, and in particular, what are the effects of using current late maturing as opposed to new early maturing varieties ?
- how might farmers diversify their production systems ?
- what sort of farms and farmers could benefit most from the innovations developed?

It will be noted that the first of these is a purely technical problem, while the other research areas exhibit increasing complexity. This project will attempt to provide answers to these questions using a whole farm simulation model built around the mechanistic and dynamic crop simulation models.

4.5. Project Expectations

It is expected that the proposed research will result in substantial benefits. ICTA was set up with a FSR orientation, and has considerable experience and expertise in this area. Information is already available for farming practices and production constraints of food crops that are grown in Guatemala (De Leon et al., 1977; Hildebrand, 1976b; Hildebrand and Reiche, 1976b; Masaya, 1988; Pachico et al., 1987). Significant databases of biological, physical and socio-economic information exist, thus facilitating the collection and generation of the information required with which to validate the crop models and to specify the socio-economic component.

The principal beneficiaries will be researchers and extensionists in ICTA, and through them the small farmers of Jutiapa, although some aggregation will be undertaken to produce information of relevance to regional planners in southeastern Guatemala.

The following benefits can be identified :

1. An organized resource data base for the Jutiapa region on soils and weather which will also benefit future studies of agriculture in this region.

2. An organized resource data base for the Jutiapa region on socio-economic and farm management data that will also benefit future studies in this region.

3. Calibrated and validated crop simulation models for dry bean, corn, and sorghum for the Jutiapa region.

4. A whole farm model developed from local available data and farm surveys, integrated with several dynamic crop models.

5. A new farm technology package which will be ready for extensionists to be tested in on-farm trials.

5. TECHNICAL WORK PLAN

The study involves four major steps: *data generation and collection*; *crop model calibration and validation*; *whole farm model synthesis and experimentation*; and *dissemination of the results*. These stages are described below.

5.1. Data Collection

5.1.1. *Physical and Agronomic Data for the Crop Models*

Dry Bean

For initial calibration of the model for Guatemalan dry bean cultivars, experiments will be conducted at the ICTA experiment station in Jutiapa. This station is the only research station in the southeastern region of Guatemala, where all breeding work and development and introduction of new material is done by ICTA researchers. Jutiapa is located at a latitude of 14.31° north, a longitude of 89.90° west, and at an altitude of 905.75 m above sea level. The annual average temperature and precipitation are 23.7° C and 1000 mm, respectively.

Preliminary trials will be conducted during the 1988 growing seasons to allow the researchers involved to become familiar with the growth analysis techniques and data collection procedures required for crop model calibration and validation. Also additional equipment in the form of a leaf area meter, digital balance, and drying oven are needed to collect all the necessary information.

Two complete trials will be conducted during 1989 at the experiment station in Jutiapa. The first trial will be planted in May or early June, after sufficient rainfall has refilled the soil profile to full capacity. Two cultivars will be planted at a row spacing of 0.4 m; total plot area will be 9 m^2 and each treatment will be replicated three times. The cultivars selected for this study are "Rabia de Gato", a black seeded early maturing cultivar, and "ICTA Ostúa", a black seeded ICTA breeding cultivar that has shown an excellent acceptability by the farmers. Plots will be fertilized according to standard recommendations from the soil testing laboratory. Furrow irrigation will be applied to reduce drought stress and optimize growing conditions during periods with no or very small amounts of rainfall. Plots will be weeded regularly, and fungicides and pesticides will be applied if needed. A similar trial will be carried out during the fall, with an expected planting date in September.

Plots will be observed twice weekly and vegetative and reproductive stages will be recorded for a ten plant random sample. Growth analysis will be performed at 10-day intervals during the vegetative growth phase and at weekly intervals during the reproductive

growth phase. A one meter sample per plot will be collected, and three uniform plants, representative for the sampled plot area, will be selected for complete breakdown of the plants into leaves, stems, petioles, shells, and seeds. Leaf area will be measured with a leaf area meter. Samples will be dried for 48 hours, and dry weight will be determined. In addition pod and seed number will be counted. The remainder of the biomass sample will also be dried for 48 hours and dry weight will be measured. At harvest maturity a two row five m long sample will be collected to determine final yield, and yield components, including total biomass, and seed and pod number. Leaf, stem, petiole, seed, pod, shell, vegetative, and total canopy weight will be calculated and expressed as g/m^2. Leaf area index (LAI), specific leaf area (SLA), apparent harvest index, shelling percentage, and growth rates will also be calculated. Statistical analysis techniques will be used to determine significant differences between either cultivars or date of planting. This information will also be used for calibration of the dry bean model and to determine the genetic coefficients for the cultivars "Rabia de Gato" and "ICTA-Ostúa" as described in one of the following sections. The data will be collected by the ICTA agronomist, Ing. Monterroso, two project supported undergraduate students, and ICTA and project supported technicians.

In the past no radiation sensor was located at the experiment station in Jutiapa, and therefore no complete weather data sets were collected to allow for a detailed calibration of the dry bean model for the growing conditions in Jutiapa. During the summer of 1988 a new LICOR-1200S minimum weather station will become available for the Jutiapa experiment station. This minimum weather station will collect and store radiation, air and soil temperature, and rainfall. Once this weather station has been installed it will be used to collect weather data for the remainder of the 1988 growing season and for the trials planned for 1989 and following years.

To study the effect of different environments on bean growth and to validate the performance of the dry bean model under farmer's conditions, six trials will be conducted on farmers' fields. These fields will be selected from the regular pool of farmer's who cooperate with ICTA's on-farm testing team for introduction of new materials. Four sites will be located in Santa Catarina Mita (14.52° N, 89.61 W, 890 m elevation), one site will be located in Asuncion Mita (14.33° N, 89.71 W, 478 m elevation) and one site will be located in Quezada (14.27° N, 90.04 W, and 980 m elevation). Four sites will be selected as "flat lands", with a slope of less than 6°, and two sites will be selected as "laderas", with a slope of more than 12°. These locations are chosen in order to be close to available weather stations in the region. Class "B" and "C" weather stations, operated by Instituto de Sismologia, Vulcanologia, Meteorologia y Hidrologia (INSIVUMEH), are located in Agua Blanca, close to Santa Catarina Mita, Asuncion Mita, and Quezada (Figure 1). These type of weather stations normally record only rainfall and temperature manually. It is expected that as part of this project three minimum weather stations will be purchased and placed at these locations for automated weather collection, including solar radiation.

The experiments in farmers' fields will be conducted during 1989 and 1990. Plots with an approximate area of 15 m^2 will be planted by the farmers, based on the normal decision process after a minimum amount of rainfall has been received during May when beans are normally planted. Two cultivars, "Rabia de Gato" and "ICTA-Ostúa" will be

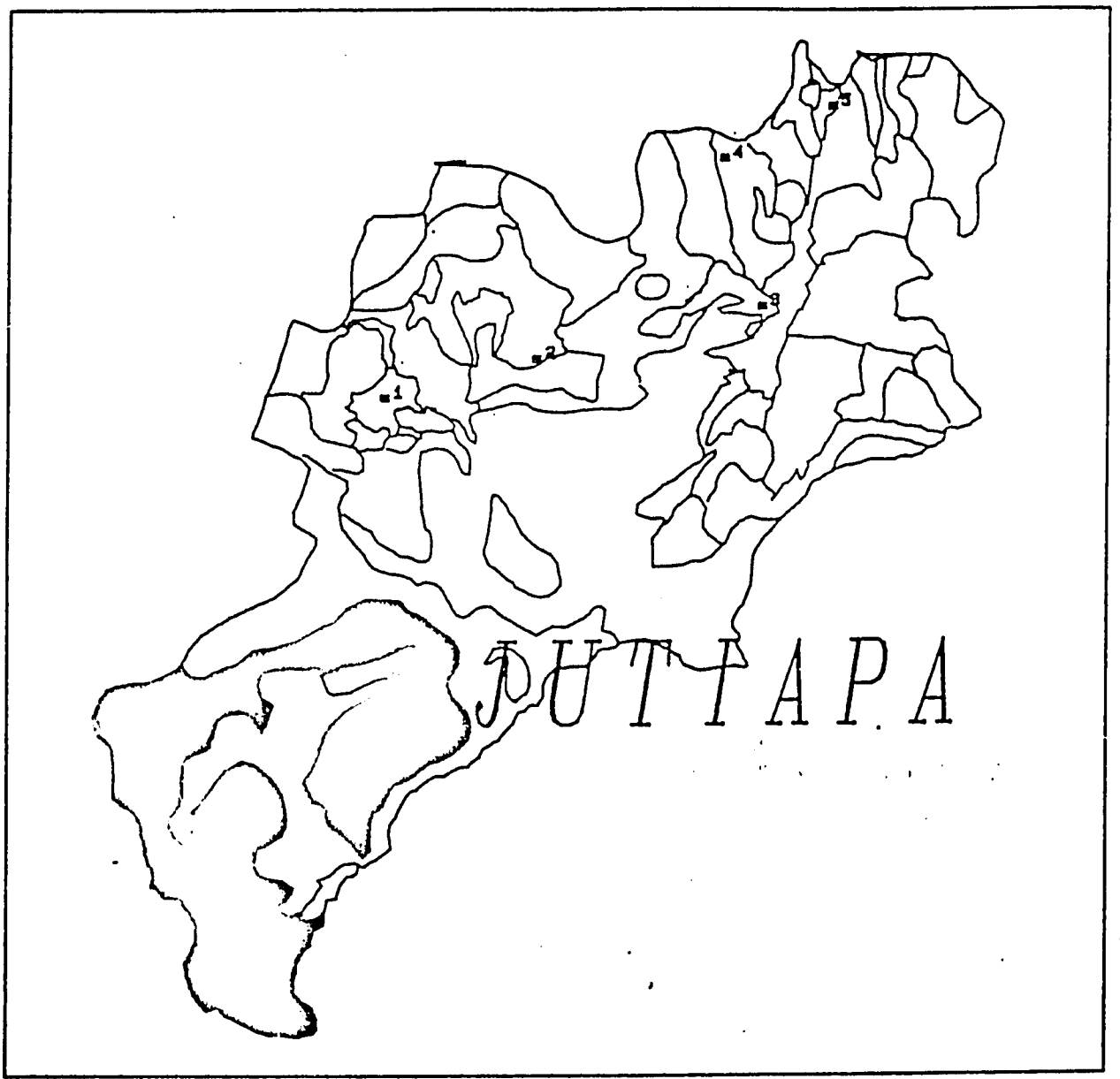

Figure 1 Soils map for Jutiapa and location of the experimental sites. 1 = Quezada, 2 = Jutiapa, 3 = Asuncion Mita, 4 = Santa Catarina Mita, 5 = Agua Blanca.

grown as a monoculture, similar to the investigations at the experiment station in Jutiapa. Soil samples will be taken to determine pre-planting water and fertility conditions. Data collected at these sites will be start of flowering, beginning seed fill, physiological maturity, and final yield and yield components. Data will be collected by the ICTA agronomist, and ICTA and project supported technicians.

Dry Bean Adaptation

After calibration of the dry bean model for the two cultivars "Rabia de Gato" and "ICTA-Ostúa", data will be collected to develop and fit characteristics of a group of 15 cultivars of known adaptation. Parameters that describe adaptation to different

environmental conditions include :

- maturity type (early, medium, late)
- dry matter distribution between the different plant components (harvest index, shelling percentage)
- response to water availability and drought stress

Beans will be planted in September, 1990, as a monoculture under irrigated and rainfed conditions. Cultivars will be characterized according to the three criteria with water availability as primary factor and dry matter distribution and maturity as secondary factor for the irrigated treatment only. Plots will be observed twice or three times per week to determine vegetative and reproductive growth stages. Growth analysis samples will be collected at 10 to 14-day intervals according to the procedures explained earlier. Results will be analyzed to verify statistical significant differences, and the data will be used to define the cultivar parameters for the dry bean model. Data will be collected by the ICTA breeder, Dr. Masaya, one project supported undergraduate student, and ICTA and project supported technicians.

Corn and Sorghum

Both corn and sorghum are an important part of the current cropping systems in Jutiapa and can not be ignored when developing a whole-farm model. One trial, therefore, will be conducted at the experiment station in Jutiapa in 1989 to collect data for calibration of the corn and sorghum computer models. Four corn cultivars, "ICTA-B-1", ICTA-B-5", ICTA-HB-83", and "Arriquin", a criollo or landrace type, and four sorghum cultivars, "ICTA-Jutiapa", "85-2", "86-1", and "Riñon", a criollo type, will be planted in June after sufficient rainfall has rewet the soil profile. Plots will be replicated three times; fertilizer will be applied according to soil test recommendations. Plots will be irrigated during periods of drought to prevent stress, and fungicides and pesticides will be applied when needed. Vegetative and reproductive development stages will reported twice weekly, and growth analysis samples will be collected at two-week intervals. Plants will be separated into stalk, leaf, ears, and grains, dried for 48 hours, and dry weight will be determined. Leaf area will be measured, and number of ears and seeds per sample will be counted. Data will be analyzed and used to calibrate the CERES-maize and CERES-sorghum models. Data will be collected by the Jutiapa station director, Ing. Carlos Heer, two project supported undergraduate students, and ICTA and project supported technicians.

The same cultivars of corn and sorghum will also be studied in farmers' fields. On-farm trials will be conducted in Quezada, Asuncion Mita, and Santa Catarina Mita during 1989 and 1990. Data collected will be start of silking, physiological maturity, and final yield and yield components. Data will be collected by the Jutiapa station director, and ICTA and project supported technicians.

Intercropping

Corn-bean and sorghum-bean are one of the broadest intercropping systems in the region. Trials, therefore, will be planted in 1990 and 1991 in Jutiapa on the experiment station and in Quezada in a farmer's field to study the interaction between dry bean with either corn or sorghum. Two dry bean cultivars, "Rabia de Gato" and ICTA-Ostúa", one corn cultivar, "ICTA-B-1", and one sorghum cultivar, "ICTA-Jutiapa", will be planted in monoculture, bean-corn, bean-sorghum, and bean-corn-sorghum intercropping. Three rows of beans will be planted between two rows of either corn or sorghum at a row spacing of 0.4 m and a plant spacing of 0.1 m. Row spacing for corn or sorghum will be 1.2 m and plant spacing will be 0.5 m. This planting scheme represents normal plant and row spacings used by the farmers in Jutiapa. Plots will be observed regularly for vegetative and reproductive stages. Growth analysis samples will be taken at 10 to 14-day intervals; sample area for dry bean will be 3 rows of 0.5 m and for corn will be one row of 1.0 m. Dry weight samples will be collected as described earlier. Final yield of both monoculture and intercropping plots will be collected for a relative large sample area to be able to measure the interaction effects between the crops grown together. Data will be analyzed statistically and will be used to define intercropping effects in both the dry bean, corn, and sorghum growth models. Data will be collected by the ICTA agronomist, two project supported undergraduate students, and ICTA and project supported technicians.

5.1.2. *Farming Systems and Socio-Economic Data*

Data Requirements

There are three principal objectives in gathering socio-economic data:

- to characterize the prevalent farming systems to enable identification of reasonably homogeneous groups to allow aggregation of response;
- to identify the important constraints on production and other factors that impinge on the farming system; and
- to isolate the major reasons for farm decision makers acting as they do (in the light of the second objective above).

These data are then used to construct relationships that can be incorporated into the whole farm model to represent the most important factors in the system, be they biological, economic, or social. In the past ICTA has carried out characterization work (for example, Leon et al., 1977; Ortiz and Cardona, 1979), and has published a continuing series of bulletins that document the cost and resource inputs to crop production for each year in Jutiapa. Some of these data will be used to help construct the whole-farm model. However, up-to-date information is required to identify all important constraints on production and the major reasons behind the farmers' decision making processes. The work plan calls for the recruitment and establishment in Jutiapa of an anthropologist, responsible for the collection of descriptive data of the extant farming systems. The information required can be listed under the following headings:

(i) Farm Characteristics

- size distribution
- type of land tenure
- soil variability
- cropping system variability

(ii) Nature of Farm System

- subsistence or cash objectives
- labor requirements over time
- male/female labor divisions
- hired labor or family
- energy requirements: manual, animal, mechanical for the various farm operations
- crops grown, rotations (carry-over effects)
- crop management: land preparation, cultivars, dates of planting and harvesting, seeding rates, variation in cropping system within farms, fertilization, irrigation, weeding, disease and pest control
- post-harvest losses
- what sort of animals kept
- major interactions between animals and crops: straw fed, manuring
- land use and methods: areas cropped each year

(iii) Prices & Costs of Production

- main cash source
- food bought, grown, sold
- prices of inputs and outputs: seasonal and between-year variation-access to purchased resources
- access to credit: what type, how, on what terms

(iv) Marketing

- general market characteristics
- pricing: stability, seasonal fluctuation, regional transportation: quality, cost, availability
- storage: type, cost, capacity
- processing
- information: what market information is available
- organizations: cooperatives
- regulations governing sale of produce

(v) Hazard Assessment

- farmers' perceptions of yield variation, the impact of pests and diseases,

rainfall variability
- measures taken to combat variation
- household reactions to crop or rain failure

(vi) Socio-cultural

- religion, customs and social institutions as these impinge on decision making or the organization of resources (e.g., labor)

(vii) Infrastructural

- roads
- credit institutions
- market institutions

(viii) Government

- price subsidies
- market interference

(ix) The Farm Family

- the decision making unit
- division of labor within the unit
- consumption
- income
- savings
- expenditure
- attitudes to risk and uncertainty
- investment/disinvestment: treatment of a surplus or a deficit

Data Collection

It is apparent that the type of information required ranges from the general (some of which ICTA has collected in the past) to the highly specific and personal. The major thrust of the work of the project supported anthropologist will be the filling of information gaps where they exist. An extensive literature exists on the development of formal and informal techniques for rural appraisal (Byerlee et al., 1980; Hildebrand, 1981; Collinson, 1981; Chambers, 1981; Rhoades, 1982; Shaner et al., 1982, for example). ICTA has extensive experience with this process. In all, three stages are envisaged for this work:

- an initial, rapid appraisal carried out using informal farmer questionnaires performed by a team comprising the Jutiapa station director, a local ICTA economist, a local ICTA agronomist, and the project supported anthropologist, to give the anthropologist a feel for the target area.

- follow-up interviewing and formal survey work on a sample of the population in the target area.
- finally, repeated farm visits over a year to a small number of households in the target area.

An important thread running through this work is to isolate the objective function of the farmer. Ultimately this might be represented in terms of multi-attribute utility functions (in their widest sense: strict economic utility may not be a very useful concept for the agriculture in Jutiapa), or in some other way that takes account of the multiple goals and trade-offs of local decision makers.

The collection and preliminary analysis of this socio-economic information will be completed in eighteen months, much of which time will be spent in the field to ensure an understanding of the major economic, social and political constraints to agricultural production in Jutiapa. The plan of work involves the following steps:

1) An assessment of the primary data collected in the past by ICTA, Dirección General de Servicios Agrícolas (DIGESA), and others, and of relevant secondary information with particular regard to its timeliness and accuracy.
2) An informal rapid appraisal survey in the target area, if necessary, with a multi-disciplinary team, including cooperation with DIGESA, on-farm research specialists, and Representantes Agropecuarios, operating along the guidelines of Hildebrand (1981) developed at ICTA. The initial target area will be pre-defined from ICTA primary data.
3) The results are analyzed to determine the sampling methodology for the formal survey to follow, involving the balance between farming system homogeneity, the required accuracy of the results, and sample size.
4) The formal questionnaire is designed and pre-tested, adjustments are carried out, and the survey work is undertaken.
5) Results are analyzed, again with a view to decreasing the sampled population to a small number that can be visited a number of times during a complete year. Detailed recording and questioning will allow a full appreciation of the dynamics of farmers' production systems, and will obtain insights into attitudes to risk and objectives.

This process constitutes a step-wise reduction in the sample size, brought about by classification of the population into increasingly homogeneous groups. As the sample size is reduced, the level of detail sought from questioning and visits to the households increases. The data will be collected by the project supported anthrologist. Support is expected from ICTA on-farm testing teams and DIGESA extensionists.

The Target Area

Because of the limited availability of climatic data which is required as input for the crop simulation models, the initial target area will include the municipio of Jutiapa, Quezada, Santa Catarina Mita, and Asuncion Mita. As noted above, weather stations are

available at these locations. An overview of the size of the target area is given in Table 1. For an informal rapid appraisal of the target area (step 2) 224 farmers will be visited. The formal questionnaire will be pre-tested with 20 farmers and the full survey will be undertaken with 448 farmers (step 4). For the final detailed questionnaire 40 farmers be visited on a regular basis by the anthropologist (step 5).

Table 1. Target area for socio-economic study, 1979 census (Ministerio de Economia, 1985).

Municipio	Farms	Area	Rural Population
	#	(manzanas)¶	#
Jutiapa	5798	34,827.57	37,702
Santa Catarina Mita	1679	13,211.96	10,992
Asuncion Mita	2676	40,519.20	17,226
Quezada	1466	10,470.88	9,668

¶ 1 manzana = 7,000 m^2

It is expected that preliminary recommendation domains for agrotechnology transfer will be able to be made after the farm-surveys and data analysis and that information will be available for the following key issues:

- What factors are pre-eminent in allowing a broad characterization of farming system type within the corn-beans-sorghum production systems in the area ?
- Can typical attitudes to risk and uncertainty be described ? If so, what are they, or if not, is it possible to correlate changing attitudes to other factors such as type of land tenure or wealth ?
- What are the over-riding factors that determine farmer or household choice?
- What does the farmer consider to be his major constraints to production?
- What are the major constraints to the uptake of new technology ?

5.2 Crop Model Calibration and Validation

Crop model calibration and validation is needed to provide credibility for the predictions of the models and a strong experimental data base for analysis of the simulated results. Crop inputs for the whole farm model are based on the crop simulation models. Therefore, accurate crop model predictions are required to define a stable base for the

overall whole farm model. In previous studies it has been shown that the dry bean model BEANGRO can be easily adapted to different environmental conditions if the necessary minimum information for model calibration is available (Hoogenboom et al., 1988b,c {see Appendix}). The experiments described in section 5.1 are so designed that all required data will be collected. Besides the crop data, climatic and soil information are the most important data which drive the model. Daily rainfall, radiation, maximum and minimum air temperature will be recorded by the LICOR-1200S minimum weather station. Soil samples collected and analyzed previously by the Soil Conservation Service (SCS) in the Jutiapa district will be used to define the parameters for each soil profile and horizon in the model.

5.2.1 *Data handling*

The measured crop growth and management data will be entered into the data base management system (DBMS) developed as part of the IBSNAT project. The forms designed for DBMS specify all the information needed for the crop models. Once all the information has been recorded, a special program is available to enter these data into the computer. Each data entry form has its own matching data form in the computer; once the data have been entered utility programs are available to print all the data, show summaries of the most important events during the experiment, or plot the weather data. There will be a different set of data files for each experiment

As part of DBMS a program generates all the input files for the crop model. There are files which describe initial soil water and fertility conditions at planting, dates and amounts of irrigation, management conditions in the form of row spacing, plant spacing, cultivar and soil type, two files which contain the plant data collected during the experiment and are used to compare measured and simulated data. The data will be entered into DBMS by a project sponsored undergraduate student.

5.2.2 *Model calibration*

Besides the input files and crop measurement files described in the previous section and which have to be redefined for each experiment, there are two permanent files which are used for all simulations. One file, called the crop parameter file, contains parameters which specify characteristics of the species *Phaseolus*, for instance maximum photosynthetic rate, respiration rate, nitrogen content of the various plant components, and many others. It is assumed that these parameters are fixed for all locations where dry bean is grown and therefore do not need to be modified. The second file, called the genetics file, contains parameters which specify characteristics for each dry bean cultivar, for instance sensitivity to temperature and photoperiod during the vegetative and reproductive growth stages, pod addition rate, seed and shell growth rate, and several others. This is the file which will need to be modified during the calibration process of the model to fit the data collected in the experiment at the Jutiapa experiment station.

Initial sets of parameters will be defined in the genetics file for the two cultivars

used in the experiments, "Rabia de Gato" and "ICTA-Ostúa". The vegetative and reproductive development phases need to be calibrated first. In the genetics file there are a total of 11 parameters to identify the most important stages during the growth of a *Phaseolus* plant. They include number of physiological days to emergence, first leaf, juvenile phase, flower induction, anthesis, first pod, fully developed pods, last pod and leaf respectively developed on the plant, physiological maturity and harvest maturity. The length of each phase is calculated through accumulators which account for degree days, photoperiod effects, drought stress and other environmental conditions which affect development. In addition the general effect of photoperiod on overall development and the sensitivity of each cultivar to photoperiod need to be defined. Not all of the vegetative and reproductive development stages listed above can be physically recorded. For model calibration, therefore, the most important stages which need to be fit to field measured data are start of anthesis, start of pod development, and physiological maturity. These three dates are discrete events which can be compared with the predictions of the model. Following the calibration for the development stages, the parameter which describes pod addition rate (#/(plant*day)) will be adjusted. The number of pods and the number of seeds as a function of planting date will be compared with the predicted values and the parameter will be adjusted so that the slope and starting point are identical. The parameters which describe shell growth rate (mg/(pod*day)), and seed growth rate (mg/(seed*day)) will be calibrated through comparing seed, pod, and shell biomass as a function of time with predicted values. Additional parameters which need calibration and verification are specific leaf photosynthetic rate, specific leaf area, number of seeds per pod, area of a single trifoliate and flower addition rate.

For proper calibration of each cultivar in the model, at least two planting dates are needed in order to check the predictions of the model under different environmental conditions. Therefore two experiments will be conducted at the experiment station in Jutiapa during 1989 and it is expected that some of the data collected during 1988 can also be used for model calibration. For the 15 cultivars in the dry bean adaptation study similar calibration procedure as described above will be used. In addition general sets of parameters will be defined which describe a particular response or adaptation for maturity type (early, medium, and late), dry matter distribution, and drought stress. These potential cultivars will then be used for strategy management and analysis studies. The dry bean model BEANGRO will be calibrated by the University of Florida supported crop modelers, Drs. Jones and Hoogenboom.

The structure of the corn and sorghum models is similar to the structure of the dry bean model (Jones and Kiniry, 1986). All models use the same file input and output structure; weather and soil input files created for the dry bean model can also be used by the corn and sorghum models. Five parameters are used in the genetics files of CERES-maize and CERES-sorghum to define the cultivar specific characteristics: growing degree days with a base of 8° C from seedling emergence to the end of the juvenile phase, photoperiod sensitivity coefficient, growing degree days from silking to physiological maturity, potential kernel number, and potential kernel growth rate. The photoperiod sensitivity coefficient will be defined first, followed by a calibration of number of days to the end of the juvenile phase and the number of days from silking to physiological maturity. Once the models predict the different stages during vegetative and reproductive

development correctly, kernel growth rate will be calibrated by comparing seed and ear weight and number as a function of time with simulated values predicted by the model. The CERES-maize and CERES-corn model will be calibrated by the University of Florida crop modelers.

5.2.3 *Model validation*

Once the model has been calibrated and parameters have been defined for the cultivars "Rabia de Gato" and "ICTA-Ostúa", model predictions need to be verified and validated for normal growing conditions in Jutiapa. For this process only a limited set of data is needed which includes number of days to flowering and physiological maturity, and final yield and yield components. Weather data will be used from the stations located in Jutiapa, Quezada, Asuncion Mita, and Santa Catarina Mita, which will be as close as possible to the weather conditions in farmer's fields. Soil conditions will be defined according to available information or actual soil samples taken at the sites. If model predictions are consistently biased, adjustments to the model will be made, similar to those planned for model calibration. The crop models will be validated by the University of Florida crop modelers, together with the ICTA investigators.

Modifications will also need to be made in the model to account for intercropping of beans with either corn, sorghum, or a mixture of beans, sorghum, and corn. This will be done through simple growth reduction functions without modeling the detailed interaction and competition in intercropping studies, which is beyond the objectives of this study. It is expected that the major competition between the different crops will be for light, available soil moisture and nitrogen. Because of the wide row spacings used for corn and sorghum, however, competition will not be as severe between the various crops as will occur in more narrowly spaced crops. Similar modifications will also be made in the CERES-sorghum and CERES-maize model to account for competition between corn and beans or sorghum and beans. Intercropping modifications in the crop models will be done by the University of Florida crop modelers.

5.2.4 *Weather and soil*

It will be necessary to run the crop models within the whole farm model for considerable periods of time. Unfortunately only historic rainfall and temperature data exist for the region, and therefore radiation needs to be generated for these four locations, based on the available climatological data and latitude, longitude, and altitude of the sites. In the current Decision Support System for Agrotechnology Transfer (DSSAT) a weather generator is installed (Jagtap et al., 1987), based on the weather generator WGEN published by Richardson and Wright (1984) and Richardson (1985). This weather generator will be checked for the sites in Jutiapa to verify that the predicted values correspond to the long term measured values for air temperature and especially rainfall. Weather generator testing will be done by the University of Florida crop modelers.

After verification of the weather generator, parameters can be calculated for each

location, and long term strategy management studies can be performed with the crop models, integrated with the whole farm model. This will allow for an unlimited number of computer experiments and simulation runs and the results of different management options can be studied in detail.

Soil profile characteristics of each farm, or sometimes of each field for highly variable soils, is another set of major input variables for the crop models. Based on already existing soil maps, soil characterization tables, SCS data from the international soil data data base, and new soil profile characterizations, a soil data base will be defined. This soil data base or soil profile file will be an input for the crop models. The major environmental conditions which can then be varied as model inputs will be climatic and soil data, including the percentage slope of the fields, or management options. As result the technology packages can be tested for a wide range of conditions.

5.3 Farm Model Synthesis and Experimentation

5.3.1. *Synthesis*

Synthesis of the whole farm model will be a continuing process throughout the project, starting after the first data have been collected from the farmers' surveys. The objective is the construction of a piece of computer software, written in FORTRAN for operation on IBM and compatible microcomputers, and transferable to larger machines if required. Two major phases are involved: first, the outlining of a conceptual model of the farming systems of interest, and second, the quantification of this conceptual model. One general form of such a model is illustrated in Figure 2. The biology and dynamic aspects of farm production will be treated through incorporation of the crop simulation models. It will not be possible to specify the exact nature of the surrounding components, nor the way in which a set of representative farm models will differ from one another until the outputs generated through the data collection stage are available. However, the treatment of a number of factors can be outlined:

Labor. The labor resource is likely to be a significant constraint on extant production systems in Jutiapa. The great majority of field work is carried out manually (Ortiz and Viana, 1982), with limited inputs of mechanized or animal traction. In the model labor will probably be treated in a scheduling fashion, taking account of labor resources within the household and the possibilities, if any exist, of hiring labor to cope with peak demands through the season.

Prices. Input and product prices will be treated in an econometric fashion, taking account of yearly and seasonal variations. Principal considerations are whether significant regional variations in prices exist; and whether small farmers can be considered to be price takers when farm response is aggregated for the region.

Consumption. This involves two aspects, household consumption of own-grown agricultural produce, and discretionary consumption. The former will be concerned with the minimum levels required to feed the family and with the possibilities of selling produce and

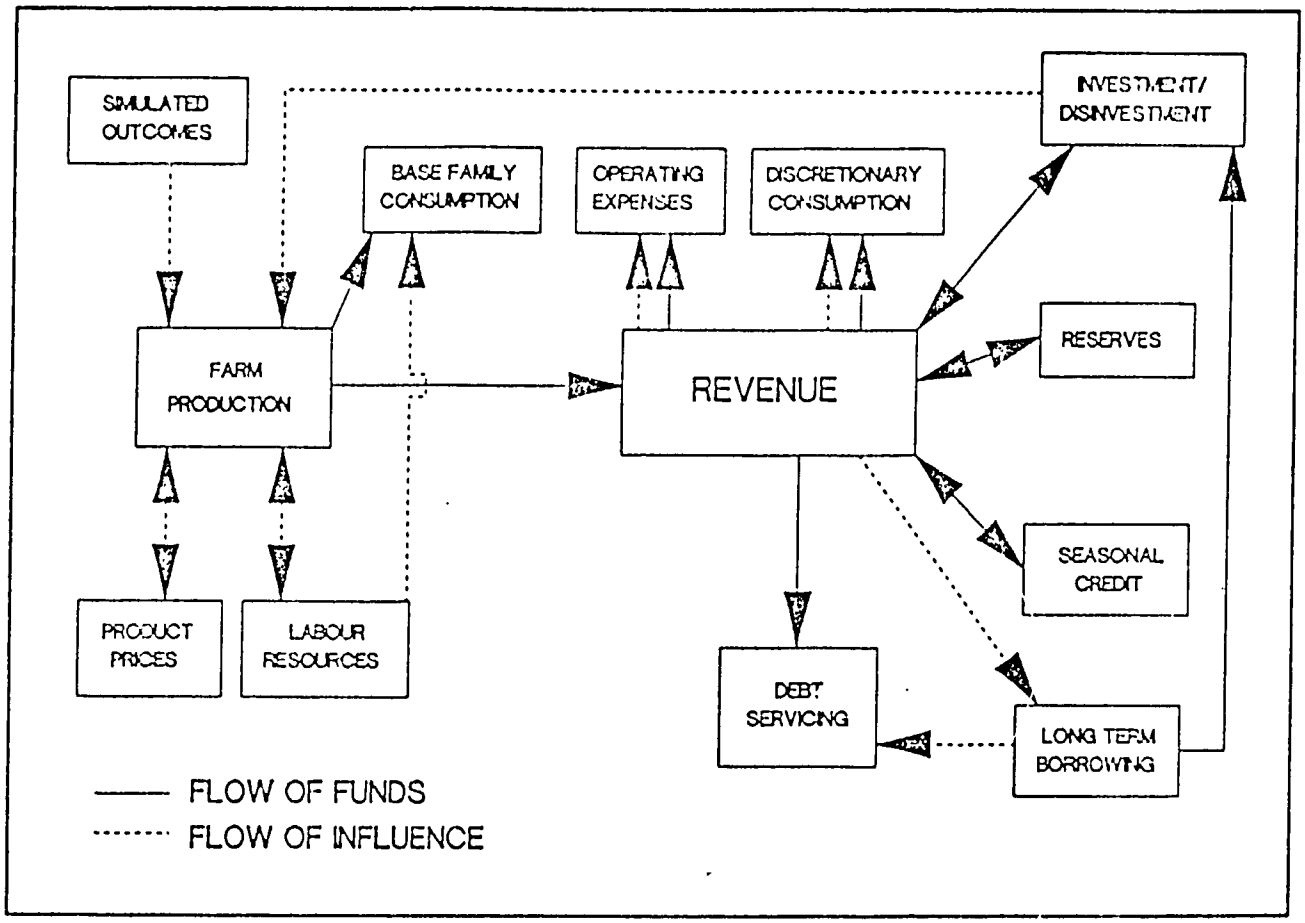

Figure 2 Conceptual whole-farm system model.

purchasing food for the household. For the latter, it may be possible to use standard techniques to estimate household discretionary consumption (Beck and Dent, 1987).

Investment/Disinvestment. Investment and disinvestment opportunities are likely to be severely limited for small holders and will depend on credit availability, among other things. The question of household action when faced with a cash surplus of deficit should prove amenable to treatment using sets of decision rules.

Household Objectives and Attitudes. The incorporation of attitudes to risk and uncertainty poses few problems with relation to neo-classical production economics, but it is likely that any utility function relevant for households in Jutiapa will be multi-attributed (Barnum and Squire, 1979), and may involve trade-offs between competing attributes. It may well be that economic utility is an insufficiently broad concept on which to base a household objective function, in which case it will be necessary to incorporate satisfying criteria. In any case, it is likely that objectives and attitudes will vary with tenurial factors, for example.

Farm Management and Environmental Characteristics. This section will involve the link between the whole farm model and crop simulation models. Variables included will be soil type, latitude, longitude, and altitude of the farm, cultivar type, row and plant spacing, irrigation and fertilization inputs, and other farm management options.

The whole farm model will be developed by the University of Edinburgh supported farming systems researcher and bio-economist, Drs. Dent and Thornton.

5.3.2. *Experimentation*

Experimentation refers to the use of the models to answer the specific questions posed above in Section 4.4

The problem of identifying promising genetic lines is soluble using the biological models, although even in this basic screening procedure there are advantages to assessing their performance in a whole farm context. Promising genetics lines from the breeding program could be characterized with model specific parameters. Long term simulations can then be run for Jutiapa and other locations, including the sites where validation data are collected, and the long term performance for different locations and conditions can be compared. This will narrow down the number of lines and will allow the selection of the best five to ten cultivars which could be further tested on farmers' fields. A start will be made with the 15 cultivars which will be characterized according to maturity responses, biomass partitioning, and drought stress. These cultivars will then be simulated for 50 to 100 seasons for at least six different locations in the Jutiapa area. Once this has been successful, theoretical lines can be produced in the model by changing one or more genetic parameters, and these lines can then be screened through computer simulations. This could identify cultivars which are drought resistant because of deep rooting systems or earliness for instance, and which can be produced or selected by the breeder through different crossing combinations (Hoogenboom et al., 1988a{see Appendix}). These simulations will be done by the ICTA breeder in cooperation with the University of Florida crop modelers.

Similar procedures can also be used to select for farmers and their fields for on testing purposes. The model can be run for many sets of different environmental conditions, soil types, and hill side slope percentages, and the results can be analyzed to select for those with the most significant differences. Fields which produce the same yield, independent of environmental, climatic, or management conditions, or differences in cultivar selection, should not be used for on-farm testing. Only a few fields representative for the entire group will be selected, and other fields with more contrasting environments, identified through the computer predictions, will be used for on farm testing. Depending on the objectives of the newly bred line, the breeder has generally a potential pool of farmers available for which he generally knows their management strategies and potential yield under a certain set of environmental conditions. These simulations will be done by the ICTA agronomist in cooperation with the University of Florida crop modelers.

In the next step the crop model and whole farm model will be integrated and run together. Simulation runs will be performed over a large number of seasons, using the stochastic weather variable generator, to produce outcome distributions that can be specified in terms of yields, net revenues, or some other measure of system performance such as the household objective function. Other sources of variation will include input and

product prices, and the probabilistic decision rules that enable management decisions to be reached within the framework of the model. The results of the simulations will be compared with sets of constraints defined from the socio-economic data base to verify that the selected management options are feasible within the environment of the resource poor farmer. The objective is to search for packages, or sets of input conditions, essentially, that are feasible in terms of the resources available to the household, that are relatively stable over the medium term, and satisfy the household's objectives. These simulations will be done by the ICTA socio-economist, in cooperation with the University of Edinburgh supported modelers.

One of the objectives of the ICTA breeding program is to select for earliness and to produce early maturing lines. The whole farm model will be used to study the effect of earliness on the socio-economic factors of the farmer and to compare the effects of early versus late maturing cultivars on the overall production system. Similarly other factors can be studied such as planting date, cultivar type, type and amount of irrigation applications, and other management inputs. An important factor which needs special attention is the production of high quality beans as a source of seed for future plantings. Different irrigation and other crop management strategies can be simulated to select for the feasible production systems. These simulations will be done by the ICTA investigators, in cooperation with the University of Edinburgh and the University of Florida supported modelers.

The whole farm model will initially be integrated with the dry bean model, followed by the corn and sorghum models. Besides diversification, the whole farm model can also study for the farm types which will benefit most from different crop management strategies, cultivar selections, or new crop introductions, which then can be targeted by DIGESA and farm-testing teams for introduction to these new techniques.

5.4 Dissemination of Results

5.4.1. *Workshop*

Research into such dynamic entities as farming systems can never be said to be complete, since the total environment of farming is continually changing. At the end of the project there will be in ICTA a number of personnel familiar with the workings of the biological models and the whole farm model. A workshop will be held at the start of year three to demonstrate the use of simulation models to interested groups of potential end-users of information generated by the crop and whole farm models.

It is expected that directors and representatives will be invited from Guatemalan agricultural organizations, including the Ministry of Agriculture, ICTA, DIGESA, Banco National de Desarrollo Agrícola (BANDESA), Instituto Nacional de Comercializacion Agrícola (INDECA), Dirección General de Servicios Pecuarios (DIGESEPE). Invitations will also be sent to international agricultural organizations including CIAT, CATIE, CIMMYT, and INCAP. It is also expected that representatives from the local AID-mission

and the regional office for Central America (ROCAP) will attend the workshop. This will represent a large group of researchers, extensionists and policy makers.

The workshop will emphasize the principal advantage of the use of valid simulation models over traditional experimentation, and the ability to assess technology packages across sites and over time. It will be important to demonstrate to the workshop participants, that the technology package developed for the Jutiapa region, can also be applied for other regions in Guatemala, or other major production areas of beans and possibly other crops in Central America. During the workshop the participants will have access to microcomputers to physically demonstrate how the models work, and what their capabilities and limitations are. The workshop will be organized by the ICTA investigators of the project, together with the University of Edinburgh and the University of Florida supported modelers.

5.5 Activities

5.5.1 *Time schedule*

```
                                Year        1           2           3
                                     |-o-o-o-o-o-|-o-o-o-o-o-o-|-o-o-o-o-o-o-|

data collection
 - crop                              ----------------------
 - socio-economic                    ----------------------------

biological model
 calibration and validation                 --------------------

biological model experimentation                       -----------------

whole farm model synthesis                 -------------------------

whole farm model experimentation                                -----------

implementation
 - workshop                                                      -
 - field work design                                                  ------
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5.5.2 *Responsibilities*

Crop data will be collected by ICTA; data collection procedures will be reviewed with University of Florida crop modelers to guarantee that all necessary information with respect to crop growth and development will be collected.

The socio-economic data will be collected by ICTA and an anthropologist hired through the project. Data collection procedures and surveys will be thoroughly discussed with the FSR modelers from the Edinburgh School of Agriculture.

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Calibration and validation of the biological models will be the responsibility of the crop modelers at the University of Florida. It is expected that throughout the project ICTA agronomists and breeders will be involved and that they will be taught how to work with and modify the models.

Crop model experimentation will be a collaboration between ICTA agronomists and breeders and University of Florida crop modelers.

Whole farm model synthesis will be the responsibility of the FSR modelers from the Edinburgh School of Agriculture, in close cooperation with the socio-economists at ICTA.

Whole farm model experimentation will be a collaboration between the ICTA socio-economists and the FSR modelers.

The workshop will be the responsibility of all people involved in this project.

Field work design and implementation will be responsibility of the ICTA research team, in close cooperation with the FSR modelers from the University of Edinburgh and the crop modelers from the University of Florida.

6. STAFF AND RESOURCES

6.1 Curricula Vitae

Name : **Porfirio MASAYA**

Position : Bean Research Program Coordinator, ICTA
Professor of Plant Breeding, Rafael Landivar University

Degrees : B.S. San Carlos University. Guatemala. 1968
M.Sc. Plant Physiology - Centro Tropical de Enseñanza e Investigación. Costa Rica
Ph.D. Plant Breeding - Cornell University, Ithaca, New York. 1978

Professional Experience :

Research assistant. Dirección General de Investigación y Control. Ministry of agriculture. 1965-1966.

Bean researcher. Dirección General de Investigación y Extension Agrícola. Ministry of Agriculture. Guatemala. 1966-1969.

Head of the Bárcenas, Experimental Station. Ministry of Agriculture. Guatemala. 1969.

Head of the Department of Basic Food Grains. Dirección de Investigación Agrícola. Ministry of Agriculture. Guatemala. 1971-1972.

Director of Agricultural Research. Ministry of Agriculture. Guatemala. 1972-1973.

Bean Research Program Coordinator. ICTA. Guatemala. 1973-1974 and 1978-1984.

Visiting Scientist. Bean Program, CIAT. Colombia. 1985.

Principal Investigator and Breeder. Bean Research Program ICTA. Guatemala. 1986-1987.

Bean Research Program Coordinator. ICTA. Guatemala. 1987-Present.

Host Country Principal Investigator. Cornell-ICTA Bean Cowpea CRSP project. 1981-Present

Principal Investigator. Central American, Mexico and the Caribbean Cooperative Project. Sub-project for early varieties. CIAT. (Swiss Government funded). 1987-Present

Consultant. Food and Agriculture Organization of the United Nations. Bean production and research. 1987.

Professor of Plant Breeding. Rafael Landivar University. Guatemala. 1987-Present

Research :

Genetic Improvement of bean varieties. On-farm research. Development of bean varieties for small landholdings. International Cooperation. Multi disciplinary research of agro-socioeconomic variables. Physiology of adaptation and yield. Seed production of beans by farmers in small landholdings.

From 1978 to date has directed and participated in the breeding of bean varieties with emphasis on their use by farmers with small landholdings. This effort produced the varieties, ICTA Quetzal, ICTA Tamazulapa, ICTA Jutiapa, ICTA Quinak-Che, ICTA Parramos, ICTA Ostúa and ICTA Valle, all of which are black small seeded types. Some of these varieties are being grown currently in Guatemala, Argentina, Chile, Mexico, Haiti and Cuba.

Awards :

Colegio de Ingenieros Agrónomos de Guatemala. 1978.
Colegio de Ingenieros Agrónomos de Guatemala. 1984.
Central American Cooperative Program for the Improvement of Food Crops. 1980.
Ulyses Rojas Order National Award. Guatemala 1983.
Interamerican Award for rural development. IICA. 1984.

Publications :

Masaya, P. 1966. Evaluación de frijoles ejoteros. XII Annual Meeting. PCCMCA. Proceedings. Managua, Nicaragua.

Masaya, P. 1968. Estudio del abonomiento y densidad de siembra en el frijol comun. Tesis de Ingeniero Agronomo. San Carlos University.

Masaya, P. 1971. Estudio de la absorcion de nutrimientos y crecimiento de raices en el frijol comun (*Phaseolus vulgaris*) M.Sc. Thesis. CATIE, Turrialba, Costa Rica.

Masaya, P. 1978. Inheritance of response to daylength in two determinate genotypes of bean, (*Phaseolus vulgaris*, L.). Ph.D. Thesis. Cornell University, Ithaca, New York.

Masaya, P. 1979. El Cultivo de frijol en el sur Oriente. Technical Bulletin No. 10. ICTA. Guatemala.

Masaya, P. L. F. Ordonez, S. Ajquejay y F. Aldana. 1980. Relación entre la asociación maíz-frijol y la distribución del rendimiento en la planta de frijol comun. XXVI Annual meeting of PCCMCA. Proceedings, Guatemala.

Masaya, P., y O. Leiva. 1980. Perspectivas del mejoramiento del frijol en Centroamerica y el Caribe. First technical meeting on seeds for Central America and the Caribbean. Proceedings. San José, Costa Rica.

Masaya, P. 1980. The ICTA case. Linkages with other national, regional and international institutions. Proceedings of the Farming Systems Symposium. Washington, D. C.

Masaya, P. 1982. La producción de frijol en Guatemala. Aspectos biofísicos y socio-economicos en relación con la tecnología de producción. Proceedings. Semana Científica de INCAP. Guatemala, Guatemala.

Masaya, P., y D. H. Wallace. 1983. Efecto de la temperatura sobre la floración y madurez de diez genotipos de frijol comun, (*Phaseolus vulgaris*, L.). XXIX Annual Meeting of the PCCMCA. Proceedings. Panamá, Panamá.

Masaya, P., y D. H. Wallace. 1983. El tiempo de madurez y algunos parametros de arquitectura de frijoles volubles del altiplano de Guatemala para el sistema maíz-frijol voluble. XXIX annual meeting of the PCCMCA. Proceedings. Panamá, Panamá.

Masaya, P. 1983. La Producción de frijol en Guatemala. *In*: Primer Curso Nacional de Frijol. ICTA. Guatemala.

Masaya. P. 1983. Objetivos, estrategias y logros del programa nacional de investigación en frijol. *In*: Primer Curso Nacional de Frijol. ICTA. Guatemala.

Masaya, P., and D. H. Wallace. 1984. The effect of elevation, (temperature), on number of days and node of flower in beans. Bean Improvement Cooperative. 27:199-202.

Masaya, P. 1984. Desarrollo de variedades para pequeños agricultores. *In*: Primer Curso internacional de frijol. ICTA-CIAT. Jutiapa, Guatemala.

Masaya, P., and D. H. Wallace. 1984. Aggressiveness of climbing beans as related to days to flower. Bean Improvement Cooperative. 27:202.

Masaya, P. 1985. Multiple effects of extended daylength on growth and yield of beans. Report to CIAT on sabbatic year. Mimeograph.

Masaya, P., and J. W. White. 1986. Efectos de dias cortos sobre el tiempo y posición de aparición de la primera flor en el frijol comun. XXXII Annual Meeting of PCCMCA. Abstracts. San Salvador, El Salvador.

Masaya, P., J. W. White and D. H. Wallace. 1986. Resultados preliminares sobre el uso

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de criterios de selección para rendimiento en generaciones tempranas de frijol comun, (*Phaseolus vulgaris*, L.). XXXII Annual Meeting of PCCMCA. Abstracts. San Salvador, El Salvador.

Masaya, P., J. W. White y D. H. Wallace. 1987. Selección en generaciones tempranas por alto rendimiento en frijol, utilizando como criterios de selección los componentes fisiológicos del rendimiento. *In*: Simposio sobre el mejoramiento de la capacidad del rendimiento del frijol comun. XXXIII Reunion Anual del PCCMCA. Proceedings. Guatemala.

Masaya, P., and D. H. Wallace. 1988. A two gene model for photoperiod temperature modulations over gene actions, regulating days to flower in bean, (Phaseolus vulgaris, L.) In preparation.

Masaya, P., and J. W. White. 1988. Plant interactions with temperature and photoperiod. Effects on adaptation and yield of beans. *In*: Beans, Research and Production. Centro Internacional de Agricultura Tropical, CIAT. In preparation.

Name : **Carlos Eduardo HEER Arana**

Position : Southeast Regional Director, ICTA.
Lecturer, Course on Experimental Design. Rafael Landivar, University.

Degrees : Ingeniero Agrónomo, San Carlos University, 1981
Master Scientiae, CATIE, Universidad de Costa Rica, 1986.

Professional Experience :

Technolology testing team, researcher, ICTA, Jutiapa, 1980 and 1982.

Responsible of training and technological linkage between ICTA-DIGESA, Region VI, Jutiapa 1981-82.

Participant in the elaboration of Production Modules for region VI. IICA-SPA. (ICTA) February 1983.

Training :

Agricultural Administration course. INTECAP. Guatemala, 1977.

Tropical Crops Irrigation. INTECAP. Guatemala.

Cotton production course. DIGESA, and Israel Embassy. Guatemala, 1980.

Applied Statistics course. ICTA-DECA, Guatemala. 1982.

Farming Systems design. CATIE -ICTA and Kellogg. Guatemala 1982.

Production, industry and trade of oil crops in Mexico, FIRA, Mexico 1983.

Soil Fertility and Fertilization course. UFRH, ICTA. Guatemala,1983.

Validation/transfer and communication methods, CATIE-ICTA, March,1987.

Training Administration. CATIE, June 1987.

Thesis Advisor :

Evaluación del efecto de Nitrógeno y Fosforo sobre los sistemas maíz-frijol-sorgo, en el Sur-Oriente del pais. 1984.

Adopción y aceptabilidad de la tecnología agrícola generada para el departamento de Jutiapa, 1984.

Publications :

Heer, C. 1981. Agronomist Thesis. Por que el agricultor realiza la asociación de cultivos en tres aldeas del departamento de Jutiapa.

Heer, C. 1986. MSc. Thesis: validación de un modelo de crecimiento de maiz (*Zea mays* L.) en monocultivo y asociado con yuca (*Manihot esculenta* C.) en el trópico.

Arze, J., C. Heer, y V. Palmieri, 1985. Programas para analizar tendencias y comportamiento de procesos agronomicos. Turrialba, Costa Rica, Departamento de Producción Vegetal, CATIE.

Arze, J., C. Heer, y V. Palmieri, 1985. Programas para análisis de datos en investigación agrícola. Turrialba, Costa Rica, Departamento de Producción Vegetal, CATIE.

Heer, C., R. Salguero, y L. Gillespie. 1988. Uso del modelo bivariado en el analisis de cultivos asociados. En XXXIV reunion Anual del PCCMCA, San Jose, Costa Rica.

Name : **Victor Armando MONTERROSO**

Position : Agronomist, Bean Program, ICTA.

Degrees : Ingeniero Agrónomo Fitotechnist - San Carlos University 1977
M.Sc. Vegetable crops - Cornell University, 1987.

Training :

Seminar: Sugar Cane Mechanization Administration. Instituto Tecnico de

Capacitación (INTECAP), Guatemala, 1976.

Seminar-workshop on photo interpretation, soil physiography and taxonomy: A practical view. Universidad de San Carlos, Dirección de Riego y Avenamiento (DIRYA), Instituto Geografico Militar (IGM), and Instituto de Ciencia y Tecnología Agrícolas (ICTA). Guatemala, 1985.

Agricultural production and Research. Instituto de Ciencia y Tecnología Agrícolas (ICTA). Guatemala, 1977. Duration, ten months.

Production and future of sugar cane. Asociación de Azucareros de Guatemala (ASAGUA), Instituto Tecnico de Capacitación (INTECAP) Guatemala 1976.

Validation/transference and communication methods, CATIE, ROCAP, KELLOG, and AID. Guatemala, 1983.

Aerial Photography. Sponsored by AID. Cornell University, USA, 1984.

Scholarships :

Agricultural Production. BID.-ICTA. Guatemala, 1977. Duration, ten months.

Research and Agricultural Production of Legumes. Sponsored by AVRDC. Taiwan ROC, 1980. Duration, six months (in English).

Master of Science in Vegetable Crops at Cornell. Sponsored by AID. USA, 1985-1987. Duration, two and a half years (in English).

Professional experience :

Instructor of the training course in research and agricultural production (III CAPA). This course was designed to give the theoretical and practical research basis to the new ICTA staff and other agronomists. 1978.

Member of the technology testing team in Jutiapa. ICTA, 1979-1983. Responsibility: to generate and verify technology (on farm research) in maize, beans, sorghum, rice and tomato.

Professor: courses, Engines and Agricultural Mechanization I and II. Rafael Landivar University. 1981-1983.

Researcher of the Bean Program in Jutiapa (South east), Chimaltenango (highlands), and Cuyuta (Pacific Coast). ICTA, 1984-1988. Responsibilities: Counterpart for ICTA in the agronomic aspect of the Project CRSP, ICTA-Cornell (AID, title XII) 1983-1985. To supervise 4 on-farm researchers (of the technology testing team), design and evaluate farming system research in Chimaltenango. In charged of the Bean Program in Cuyuta and Pacific Coast and research in hillside farming

("laderas") in Jutiapa, 1988. Actually, conducting the first growth analysis studies for validation of the BEANGRO model in Jutiapa.

Publications :

Monterroso, V. A. 1977. Monografía de la aldea San Matias (Jutiapa) con enfasis en riegos.

Monterroso, V. A. 1978. Evaluación de tres sistemas de siembra a dos niveles de fertilización en maiz-frijol-sorgo asociados, en el sur oriente de Guatemala. Thesis USAC.

Monterroso, V. A. 1979. Factores que influyen en la producción de frijol en el sur oriente de Guatemala. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Honduras.

Monterroso, V. A. 1979. Epocas de siembra de frijol en el sur oriente de Guatemala. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Honduras.

Monterroso, V. A. 1980. Response of 14 soybean cultivars with minimum management input in Taiwan. Internal Report, AVRDC. Republic of China.

Monterroso, V. A. 1982. Evaluación de 13 variedades de soya en Jutiapa y la costa sur de Guatemala. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Costa Rica.

Orozco, S. H., and V. A. Monterroso. 1982. Evaluación de productos químicos para el control de plagas de insectos y malezas de frijol en el sur oriente de Guatemala. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Costa Rica.

Monterroso, V. A. 1982. Control químico y varietal de mosaico dorado en siembras de frijol en primera y segunda en Jutiapa. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Costa Rica.

Diza, J. M., and V. A. Monterroso. 1984. Variedades mejoradas de frijol negro arbustivo (Phaseolus vulgaris) para altitudes mayores a los 1500 m. Su proceso de generación dentro de la metodologia de ICTA. Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Honduras, 1984.

Orozco, S. H., and V. A . Monterroso. 1984. Algunos sistemas de producción de frijol en el altiplano central de Guatemala. *In* : Curso de Producción de frijol [J. Diaz and P. Masaya, eds.]. ICTA, Guatemala,

Wien, C., and V. A. Monterroso. 1987. Flower and pod abscission under stress conditions in snap beans. American Society For Horticultural Science. Florida, Abstracts.

Monterroso, V. A. 1988. Altas temperaturas y la caida de flores y frutos en frijol (*Phaseolus vulgaris* L.). Annual meeting Programa Cooperativo Centroamericano de Mejoramiento de Calidad Alimenticia (PCCMCA). Costa Rica.

Monterroso, V. A. 1988. Flower and pod abscission due to heat stress in beans. Cornell University, M.Sc. Thesis. Cornell University.

Wien, H., and V. A. Monterroso. 1988. Flower abscission and fruit set in beans. Annual Report Bean Improvement Cooperative 31.

Monterroso, V. A., and H. Wien. 1988. Effect of high temperature on pod set of *Phaseolus*

vulgaris L. Annual Report Bean Improvement Cooperative 31:160.

Name : J. W. JONES

Position : Professor, University of Florida

Degrees : B.S. Agricultural Engineering - Texas Tech Univ. 1967
M.S. Agricultural Engineering - Mississippi State Univ. 1970
Ph.D. Agricultural Engineering - North Carolina State Univ. 1975

Professional experience :

Research Agricultural Engineer, USDA-ARS, Mississippi State, MS. 1967-1975.

Research Agricultural Engineer, USDA-ARS, and Assistant Professor, Agricultural Engineering Department, Mississippi State University. 1975-1977.

Associate Professor, Agricultural Engineering Department, University of Florida, Gainesville, Florida. 1978-1981.

Professor, Agricultural Engineering Department, University of Florida, Gainesville, Florida. 1982-Present.

Research :

Mathematical modeling of crop, soil, and insect population dynamics. Instrumentation and computer control of experiments for model development. Computer simulation of crop production systems, integrating crop, soil, pest, weather, and management components. Interdisciplinary research on crop systems. Development of microcomputer based expert systems for crop production decision aids. Design and oversee development of Decision Support System for Agrotechnology Transfer. User-oriented crop models on microcomputers for soybean, peanut, and dry bean.
Principal or Co-principal Investigator on currently-active grants: about $200,000 per year.

During last ten years, Principal or Co-principal Investigator of grants totaling over $2 million.

Teaching :

Developed and taught graduate level course entitled "Simulation of Agricultural and Biological Systems" in the Agricultural Engineering Department at the University of

Florida. (AGE5646 - taught each Spring Semester; 3-semester hours).

Co-developer of short course, "Simulation of Crop Production Systems", taught August, 1985, to international audience. Chairman of committee responsible for the course.

Awards :

National ASAE Student Award
"Aggie of the Year" - Texas Tech University
Top Engineering Graduate - Texas Tech University (1967)
Tau Beta Pi
Alpha Epsilon
Sigma Xi
Alpha Zeta
Phi Kappa Phi
Outstanding Young Men of America

Professional Affiliations :

Co-Editor, Journal of Agricultural Systems
American Society of Agricultural engineers
American Society of Agronomy
Crop Science Society of America
Soil Science Society of America

Publications :

Berger, R. D. and J. W. Jones, 1985. A general model for disease progress during changing host growth with functions for variable latency and lesion growth. Phytopath. 75:792-797.

Boggess, W. G., G. D. Lynne, J. W. Jones, and D. P. Swaney. 1983. Risk-return assessment of irrigation scheduling decisions. S. Jour. Ag. Econ. July, 1983. pp. 135-143.

Boote, K. J., J. W. Jones, J. W. Mishoe, and R. D. Berger. 1983. Coupling Pests to Crop Growth Simulators to Predict Yield Reductions. Phytopathology, 73(11):1581-1587.

Jacobson, B., J. W. Jones, P. Jones. 1987. Tomato greenhouse environment controller: Real-time expert system supervisor. ASAE Paper No. 87-5022. Amer. Soc. Agr. Engr., St. Joseph, MI. 49005.

Jagtap, S. S. and J. W. Jones. 1987. Risk assessment using crop simulation models. ASAE Paper No. 87-3534. Amer. Soc. Agr. Engr., St. Joseph, MI 49085.

Jones, J. W. 1985. Using expert systems in agricultural models. Ag. Eng. 66(7):21-23.

Jones, J. W. and B. Zur. 1984. Simulation of Possible Adaptive Mechanisms in Crops Subjected to water Stress. Irrig. Sci. 5:251-264.

Jones, J. W., B. Zur, J. M. Bennett. 1986. Interactive Effects of Water and Nitrogen Stress on Carbon and Water Vapor Exchange of Corn Canopies. Ag. & Forest Met. 38:113-126.

Jones, J. W., H. Beck, R. M. Peart, and P. Jones. 1986. Applications of Expert System

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Concepts to Agrotechnology Transfer. Proceedings, ISSS Congress, Hamburg, West Germany.

Jones, J. W., J. W. Mishoe, G. G. Wilkerson, J. L. Stimac, and W. G. Boggess. 1986. Integration of crop and pest models. In Integrated Pest Management on Major Agricultural Systems. R. E. Frisbie and P. L. Adkisson (eds.) Texas Agr. Exp. Sta. MP-1616. Texas A&M University. College Station, TX.

Jones, Pierce, J. W. Jones, and L. H. Allen, Jr. 1985. Seasonal carbon and water balances of soybeans grown under stress treatments in sunlit chambers. Trans. ASAE 28(6):2021-2028.

McClendon, R. W., W. D. Batchelor, and J. W. Jones. 1987. Insect pest management with an expert system coupled crop model. ASAE Paper No. 87-4501. Amer. Soc. Agr. Engr., St. Joseph, MI 49085.

Mishoe, J. W., J. W. Jones, D. P. Swaney, and G. G. Wilkerson. 1984. Using crop and pest models for management applications. Agr. Systems 15:153-170.

Swaney, D. P., J. W. Jones, W. G. Boggess, G. G. Wilkerson, and J. W. Mishoe. 1983. Real-Time Irrigation Decision Analysis Using Simulation. TRANSACTIONS of ASAE, 26(2):562-568.

Swaney, D. P., J. W. Jones, and J. W. Mishoe. 1986. A Combined Simulation-Optimization Approach for Predicting Crop Yields. Ag. Systems (20) pp. 133-157.

Wilkerson, G. G., J. W. Jones, K. J. Boote, K. T. Ingram, and J. W. Mishoe. 1983. Modeling soybean growth for crop management. Trans. ASAE. 26:63-73.

Name : **Gerrit HOOGENBOOM**

Position : Post doctoral Associate, University of Florida

Degrees : B.Sc. Horticulture - Agricultural University, Wageningen, 1978
M.Sc. Horticulture, Theoretical Plant Production Ecology - Agricultural University, Wageningen, the Netherlands, 1981
Ph.D. Agronomy and Soils (Crop Science) - Auburn University, 1985

Professional Experience :

Visiting Research Scientist, Scottish Horticultural Research Institute, Invergowrie, Scotland. 1977-1978.

Visiting Research Scientist, Agricultural Research Organization, Volcani Center, Bet Dagan, Israel. 1979.

Research Assistant, Department of Agronomy and Soils, Auburn University, Alabama. 1981-1985.

Post doctoral Associate, Department of Agricultural Engineering, University of

Florida, Gainesville, Florida. 1985-Present.

Research :

Development of a computer model which simulates vegetative and reproductive growth and final yield of common beans (*Phaseolus vulgaris* L.). To conduct field experiments with common beans for calibration of the bean simulation model. Cooperation with other researchers to collect minimum data sets for further validation of the model at other locations. Development of subprograms which simulate nitrogen uptake, fixation, and remobilization in leguminous crops. Modeling of crop growth in general with special emphasis on shoot-root relationships, root growth and soil water uptake as a function of different water management regimes.

Awards :

STEP Award. American Society of Agronomy, November 1984.
Graduate Student Travel Award. Auburn University, December 1984.
Sigma Xi Research Award. Auburn University, May 1986.
Gamma Sigma Delta
Sigma Xi

Professional Affiliations :

American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
Soil and Crop Science Society of Florida
Society for Computer Simulation
American Society for Plant Physiologists
American Peanut Research and Education Society
International Society of Root Research
Bean Improvement Cooperative
Dutch Institute of Agricultural Engineers
Royal Dutch Institute for Agriculture

Publications :

Huck, M. G., C. M. Peterson, G. Hoogenboom, and C. D. Busch. 1986. Distribution of dry matter between shoots and roots of irrigated and nonirrigated soybeans. Agronomy Journal 78:807-813.

Hoogenboom, G., M. G. Huck, and D. Hillel. 1987. Modification and testing of a model simulating root and shoot growth as related to soil-water dynamics. pp. 331-387. *In*: [D. Hillel ed.] Advances in Irrigation, Vol. 4. Academic Press, Orlando, Florida.

Hoogenboom, G., M. G. Huck, and C. M. Peterson. 1987. Root growth rates of soybean as affected by drought stress. Agronomy Journal 79:607-614.

Hoogenboom, G., C. M. Peterson, and M. G. Huck. 1987. Shoot growth rates of soybean as affected by drought stress. Agronomy Journal 79:598-607.

Hoogenboom, G., C. M. Peterson, and M. G. Huck. 1987. Computers help explain environmental effects on plant growth. Highlights of Agricultural Research 34(3) : 3. Alabama Agricultural Experiment Station, Auburn University, Auburn, Alabama.

Huck, M. G., G. Hoogenboom, and C. M. Peterson. 1987. Soybean root senescence under drought stress. pp. 109-121. *In*: [H. M. Taylor ed.] Minirhizotron Observation Tubes: Methods and Applications for Measuring Rhizosphere Dynamics. ASA special publication no. 50. American Society of Agronomy, Madison, WI.

Blake, J. I., and G. Hoogenboom. 1988. A dynamic simulation of Loblolly Pine (*Pinus taeda* L.) seedling establishment based upon carbon and water balances. Canadian Journal of Forest Research. (In press).

Hoogenboom, G., M. G. Huck, and C. M. Peterson. 1988. Predicting root growth and water uptake under different soil water regimes. Agricultural Systems 26(4) 263-290.

Hoogenboom, G., M. G. Huck, C. M. Peterson, and A. Goli. 1988. Automated micro-analysis for starch and sucrose in single soybean leaflets. Journal of the Association of Analytical Chemists 71(4):844-848.

Hoogenboom, G., J. W. Jones, and J. W. White. 1988. Use of models in studies of drought tolerance. Proceedings Bean Drought Workshop. Centro Internacional de Agricultura Tropical, Cali, Colombia, South America. (In press)

Hoogenboom, G., J. W. White, and J. W. Jones. 1988. A computer model for the simulation of bean growth and development. Proceedings Third International Bean Trials Workshop. Centro Internacional de Agricultura Tropical, Cali, Colombia, South America. (In press).

Lal, H., G. Hoogenboom, J. W. Jones, and R. M. Peart. 1988. Application of crop models for technology testing and transfer. Proceedings of the 2nd International Conference on Computers in Agricultural Extension Programs. February 10-11, 1988. Lake Buena Vista, Florida. (In press).

Name : **John Barry DENT**

Position : Professor, University of Edinburgh
Head of Division of Agricultural Resource Management, Edinburgh School of Agriculture.

Degrees : B.Sc. Agriculture - University of Reading. 1960
MAg.Sci. Agriculture - University of Reading. 1962
Ph.D. Agriculture - University of Aberdeen. 1964

Professional Experience :

MAFF Post Graduate Scholar, Department of Agriculture, University of Reading. 1960-1962.

Research Fellow, Department of Agriculture, University of Aberdeen. 1962-1964.

Lecturer, Department of Agriculture, University of Reading. 1964-1970.

Queen Elizabeth II Fellow, University of New England, Armidale, Australia. 1968-1970.

Reader, Department of Agriculture and Horticulture, University of Nottingham. 1971-1974.

Professor and Head of Department of Farm Management and Rural Valuation, Lincoln University College of Agriculture, New Zealand. 1974-1986.

Director, Agricultural Economics Research Unit, Lincoln University College of Agriculture. 1976-1981.

Professor, Department of Agriculture, University of Edinburgh, 1986-Present.

Head, Division of Agricultural Resource Management, Edinburgh School of Agriculture. 1986-Present.

Research :

Computer assisted business management procedures for agricultural enterprises using Expert Systems and Database Management methods. Computer simulation of behavioral characteristics of farmers to provide mechanisms to assess national and EEC agricultural policy options. Development of methodology to assess land and other rural resource use strategies.

Teaching :

Teaching courses at undergraduate, honors and Masters degree level.

Currently supervising 6 PhD students, several of whom are members of my Divisional staff.

Consultancies :

UNESCO consultant on computing in Indian Agricultural Universities, 1976

NZ AID, Fiji, 1980

U.S. Agency for International Development Project Technical Adviser on the transfer of technology in tropical agriculture, 1984-Present.

Adviser on Tertiary Agricultural Education Development to Government of Indonesia, 1984-Present.

Awards :

Fellow British Institute of Management
Fellow Royal Society of Arts

Professional Affiliations :

Co-Editor, Agricultural Systems Journal.
Member of Editorial Board, Research and Development in Agriculture, Outlook on Agriculture and Agricultural Administration and Extension.

Publications :

Dent, J. B., and J. R. Anderson. 1971. Systems Analysis in Agricultural Management, John Wiley: Sydney [translated also into Spanish].

Dent, J. B., and V. V. N. Murty (eds). 1978. Agricultural Systems, Theory and Application, Punjab Agricultural University, Ludihana, India.

Dent, J. B., and M. J. Blackie. 1979. Systems Simulation in Agriculture, Applied Science: London.

Dent, J. B., and M. J. Blackie. 1979. Information Systems for Agriculture, Applied Science: London.

Dent, J. B., and A. C. Beck. 1981. A systems view of world food production, in Yearbook of Science and Technology, New York: McGraw Hill, p82-84.

Dent, J. B., and A. C. Beck. 1983. Risk planning for farmers. Agric. Economist, 4(2):22-26.

Dent, J. B., S. R. Harrison, and K. B. Woodford. 1986. Farm Planning: Concepts and Practices Using Linear Programming, Butterworths: Sydney. pp 210.

Beck, A.C., and J. B. Dent. 1987. A farm growth model for an extensive pastoral production system. Austr. J. Ag. Econ, 31(1):29-44.

Dent, J. B., and P. K. Thornton. 1987. IBSNAT crop models in a socio-economic whole farm framework. Agro-Technology News, University of Hawaii, September 1987, pp 1,4-7.

Dent, J. B., and W. S. SCANLAN. 1987. Database management for farm systems development. 1st Int. Symp on Agricultural Engineering Systems, China.

Dent, J. B. and P. K. Thornton. 1988. The Role of Biological Simulation Models in Farming Systems Research, Agric. Admin & Extension, 29(2):111-122.

McGregor, M. J. and J. B. Dent. 1988. A Multiple Objective Approach to Resolving Resource Use Conflict in Agriculture. 17th Seminar of EAAE, Debrecen, Hungary, 13-16 September 1988.

Dent, J. B. 1988. Towards an Agro-Industrial Future: Farming Systems. 6th Royal Show International Symposium, Stoneleigh, Kennilworth. 28th June - 4th July, 1988.

Name : **Philip Kenneth THORNTON**

Position : Senior Research Fellow, University of Edinburgh.

Degrees : B.Sc. (Hons) Agriculture, class 2.1 - Reading University, 1979.
Ph.D. Farm Management and Rural Valuation - Lincoln College, University of Canterbury, New Zealand. Thesis title: Information System Design for the Rationalization of Fungicide Use: the Control of *Puccinia hordei* Otth..

Professional experience :

Extensive travelling has been undertaken throughout Europe, in the US (1974), New Zealand and Australia (1981-1984), Africa (1984), and Latin America (1985-1987).

Overseas work experience, including consultancies, has been gained in the US, Colombia, Venezuela and Guatemala, over the period 1984 to Present.

Post-doctoral fellowship Centro Internacional de Agricultura Tropical, Colombia, in the Cattle Production Systems section of the Tropical Pastures Program as a bioeconomist, 1984-1987.

Senior Research Fellowship has been held at the University of Edinburgh funded by the United States Agency for International Development, 1987-Present.

Book review editor, Agricultural Systems, January 1988-Present.

Awards :

Commonwealth Scholarship, administered by the government of New Zealand, February 1981 to January 1984.

The MacMillan Brown Agricultural Scholarship of the University of Canterbury, New Zealand, 1981.

Professional Affiliations :

Agricultural Economics Society

Publications :

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6.2 Institutional Facilities

The headquarters of ICTA are located in Guatemala City and will soon be moved to a new building which is currently being constructed. All administrative support is handled through ICTA headquarters; duplicating and printing facilities are available. The coordinator of the bean program is stationed in Guatemala and he has two secretaries available for administrative support services. ICTA also maintains an extensive agricultural library. A special soils division of ICTA has a soils analysis laboratory which is well equipped to analyze soil samples and recommend fertilizer application rates.

At the ICTA experiment station in Jutiapa 6 ha of well-maintained land available for trials with beans, corn, sorghum and other crops. Water pumps are installed to apply irrigation through furrows. Equipment available to cultivate the soil include tractors, plows, and disks. Field technicians help to prepare the land, spray pesticides and fungicides, apply furrow irrigation, and do other regular crop management tasks. These technicians can also be requested to help with the collection of plant data during the growth analysis studies and for final harvest. Storage facilities are available for drying and storing bean and other type seeds.

At Jutiapa there is a group of 14 researchers and extensionists stationed from ICTA and DIGESA who are involved in socio-economic data collection. They are supervised by the regional director, Ing. Carlos Heer who is a principal investigator in this project. Some of these people could be used for short term secondary data collection, dynamic diagnosis, and farmers' surveys. These people can also introduce the anthropologist to the farmers in Jutiapa and help him/her to become acquainted with the region and the farm surveys and existing data sets. In addition there is a library at the station which has most of the reports of previous studies and surveys of the Jutiapa district.

ICTA already has a system available for contacting farmers and has procedures developed for cooperation between ICTA researchers and farmers for on-farm trials. In most cases the farmer will pay for the seeds and other materials involved, because he is aware of the importance of the research being conducted and of being selected as one of the example farmers to demonstrate these trials to other farmers.

The Department of Agricultural Engineering at the University of Florida has a

special Cropping Systems Laboratory, where several IBM microcomputers, line and laser printers, a plotter, and a digitizer are being used for development, calibration and validation of crop models, expert systems, and other software packages for application in agriculture. The decision support system DSSAT is installed on several computers for field data entry, retrieval and creation of computer files. DSSAT also includes a weather generator to create long term weather data, and a management strategy program which will simulate long term crop growth and development responses as a function of various management inputs. A Geographical Information System (GIS) is in the process of being tested for the capabilities of integrating the data bases stored in GIS with the available crop models. A Sun minicomputer has recently been installed by the department to handle more complex modeling jobs or calculation intensive programs. Vax and IBM minicomputers are available in the Institute of Food and Agricultural Sciences and U.F. Faculty Support Computer Center, respectively. The IBM minicomputer has the latest SAS packages installed for complete statistical analysis of the field data. For large statistical jobs an IBM mainframe at the North East Regional Data Center (NERDC), located on campus, can be used.

The University of Edinburgh has excellent research facilities with which to offer backup support to the project. Departments of particular relevance include computer science, agriculture and anthropology. The first of these is one of the best-equipped in any United Kingdom university. The School of Agriculture has strong links with developing countries, through short courses and post-graduate teaching, and also has a thriving tropical agricultural consultancy business. The anthropology department also has a great tradition in short-term consultancies for various agencies in many countries of the world, and their expertise in the economic-anthropological aspects of the proposed research is considerable.

7. SCIENTIFIC COLLABORATION

The proposed research is to be split three ways: between ICTA, and the Universities of Florida and Edinburgh. The positions of the crop modeler at the University of Florida and the bio-economist at the University of Edinburgh are maintained by IBSNAT core funds. For the University of Edinburgh, no funds are requested at all. For the University of Florida, the budget in section 8 specifies various inputs, including some travel. The project supported anthropologist will be hired through ICTA.

ICTA will be responsible for crop data collection, and their input for the farm surveys will be indispensable (expertise, farmers, interviewers with wide experience of farming in the area).

Validation of the crop models will be handled between ICTA and the University of Florida. The University of Edinburgh will be responsible for the initial synthesis of the whole farm model, but this activity will be increasingly handled by ICTA in years 2 and 3 of the project. Both of these activities will thus provide substantial hands-on training experience.

Experimentation with the biological and whole farm models will be undertaken by

ICTA, and inputs to the workshop at the start of year three will come from all three institutions.

The benefits to the parties involved arising from participation in the proposed research are various:

- ICTA will gain a highly useful working tool for enhancing the efficiency of field experimentation, and a core of personnel competent in modeling to make adjustments and changes as these become necessary.
- the University of Florida will obtain a number of first-class data sets for calibrating and validating the dry bean, corn and sorghum models.
- the University of Edinburgh will obtain experience in whole farm modeling that can be put to use in other regions in the tropics and in temperate zones.

8. BUDGET

Total combined budget for ICTA, Guatemala, and the University of Florida.

	US $ year		
	1	2	3
Personnel			
Anthropologist	7,000.00	7,000.00	0.00
Technicians	6,000.00	6,000.00	2,000.00
Student assistants	2,700.00	2,700.00	0.00
Student labor	3,000.00	3,000.00	1,197.08
Data processor 0.70 FTE [1]	0.00	0.00	0.00
Agronomist 0.40 FTE [1]	0.00	0.00	0.00
Socio-economist 0.30 FTE [1]	0.00	0.00	0.00
Plant breeder 0.25 FTE [1]	0.00	0.00	0.00
Bio-economist 0.40 FTE [2]	0.00	0.00	0.00
Crop modeler 0.25 FTE [3]	0.00	0.00	0.00
Agric. Systems modeler 0.05 FTE [3]	0.00	0.00	0.00
FSR Specialist 0.05 FTE [2]	0.00	0.00	0.00
Equipment			
Microcomputer	5,000.00	0.00	0.00
Leaf area meter	6,600.00	0.00	0.00
Minimum weather stations (3)	5,100.00	0.00	0.00
Oven and plant sample drier	2,500.00	0.00	0.00
Digital balance	1,000.00	0.00	0.00
Backpack motor sprayer (2)	1,500.00	0.00	0.00
Camera	500.00	0.00	0.00
Seed moisture meter	600.00	0.00	0.00
File Cabinets (2)	300.00	0.00	0.00
Desks (2)	300.00	0.00	0.00
Computer desk	250.00	0.00	0.00
Book Shelf	100.00	0.00	0.00

[1] Supported through collaboration with ICTA-Guatemala.

[2] Supported through collaboration with the University of Edinburgh.

[3] Supported through collaboration with the University of Florida.

Transportation			
Vehicles or trucks (2)	20,000.00	0.00	0.00
Gasoline and diesel	2,000.00	2,000.00	1,000.00
Maintenance	1,800.00	1,800.00	900.00
Materials and Supplies			
Materials	4,500.00	3,500.00	1,450.00
Xerox, telephone, telex, stamps	750.00	750.00	400.00
Training			
Workshop	0.00	0.00	5,000.00
Travel			
US-Guatemala	10,000.00	8,000.00	4,000.00
Domestic	2,800.00	2,800.00	1,400.00
International	500.00	2,000.00	1,500.00
	------.--	------.--	------.--
Sub total	84,800.00	39,550.00	18,847.08
Other Expenses			
Indirect Costs (UF)	3,029.00	2,563.00	1,210.92
	------.--	------.--	------.--
Total	87,829.00	42,113.00	20,058.00
Grand Total			150,000.00

Budget for ICTA, Guatemala (US $).

	year		
	1	2	3
Personnel			
Anthropologist	7,000.00	7,000.00	0.00 (1)
Technicians	6,000.00	6,000.00	2,000.00 (2)
Student assistants	2,700.00	2,700.00	0.00 (3)
Data processor 0.70 FTE	0.00	0.00	0.00
Agronomist 0.40 FTE	0.00	0.00	0.00
Socio-economist 0.30 FTE	0.00	0.00	0.00
Plant breeder 0.25 FTE	0.00	0.00	0.00
Equipment			
Microcomputer	5,000.00	0.00	0.00 (4)
Leaf area meter	6,600.00	0.00	0.00 (5)
Minimum weather stations (3)	5,100.00	0.00	0.00 (6)
Oven and plant sample drier	2,500.00	0.00	0.00 (7)
Digital balance	1,000.00	0.00	0.00 (8)
Backpack motor sprayer (2)	1,500.00	0.00	0.00 (9)
Camera	500.00	0.00	0.00 (10)
Seed moisture meter	600.00	0.00	0.00 (11)
File Cabinets (2)	300.00	0.00	0.00 (12)
Desks (2)	300.00	0.00	0.00 (13)
Computer desk	250.00	0.00	0.00 (14)
Book Shelf	100.00	0.00	0.00 (15)
Transportation			
Vehicles or trucks (2)	20,000.00	0.00	0.00 (16)
Gasoline and diesel	2,000.00	2,000.00	1,000.00 (17)
Maintenance	1,800.00	1,800.00	900.00 (18)
Materials and Supplies			
Materials	4,500.00	3,500.00	1,450.00 (19)
Xerox, telephone, telex, stamps	750.00	750.00	400.00 (20)
Training			
Workshop	0.00	0.00	5,000.00 (21)
Travel			
Domestic	2,800.00	2,800.00	1,400.00 (22)
International	500.00	2,000.00	1,500.00 (23)
	------.--	------.--	------.--
Total	71,800.00	28,550.00	13,650.00
Grand Total			114,000.00

Budget for the University of Florida (US $) [4].

	year		
	1	2	3
Personnel			
Student labor (OPS)	3,000.00	3,000.00	1,197.08 (24)
Crop modeler 0.25 FTE	0.00	0.00	0.00
Agric. Systems modeler 0.05 FTE	0.00	0.00	0.00
Travel			
US-Guatemala	10,000.00	8,000.00	4,000.00 (25)
	------.--	------.--	------.--
Sub total	13,000.00	11,000.00	5,197.08
Other Expenses			
Indirect Costs (23.3 %)	3,029.00	2,563.00	1,210.92
	------.--	------.--	------.--
Total	16,029.00	13,563.00	6,408.00
Grand Total			36,000.00

Budget justification.

1. An anthropologist will collect the socio-economic data described in the data collection procedures. The person will be supervised by the socio-economist (Carlos Heer) and will cooperate closely with ICTA and DIGESA people stationed in Jutiapa.

2. Technicians will help with the collection of growth analysis data for dry bean, corn, and sorghum field studies. Especially the separation of the plants into different components is very labor intensive.

3. A total of six undergraduate students will be involved for their undergraduate thesis projects as part of their study for a Ingenieer Agronomo (B.Sc) degree. Each person will be responsible for one growth analysis experiment with either beans, corn, or sorghum, and will receive a small compensation for his work. The undergraduate students will be supervised by Dr. Masaya, and Ing. Monterroso. .

[4] Travel by the bio-economist will be reimbursed through the University of Florida.

4. Currently no microcomputer is located at the experiment station in Jutiapa. A complete IBM-AT compatible machine with a 82287 processor will be purchased, including a harddisk, math-coprocessor, color monitor, battery powered back-up power supply, printer, modem, and the necessary software. The microcomputer will be used to enter the socio-economic data, create a data base, and run the crop and whole farm model.

5. The leaf area meter will be used to measure the leaf area of plant samples collected during the growth analysis studies. Any existing procedures, e.g. measuring length and width of each leaf, tracing the leaves and weighing the paper, or xeroxing the leaves are extremely labor intensive and very inaccurate. Leaf area is an important state variable predicted by the model and needs to be validated with accurately measured leaf area samples.

6. Currently the existing INSIVUMEH weather stations in the Jutiapa area collect only maximum and minimum air temperature and rainfall, which are recorded manually. Climatic data required for the models include radiation, air temperature, and rainfall. The LICOR-1200S minimum weather stations will record all data necessary for the models automatically and will store up to 200 days of data. The minimum weather stations will be placed at the current locations where rainfall and temperature are being recorded, e.g. Quezada, Asuncion Mita, and Agua Blanca.

7. There is no plant sample drier at the Jutiapa experiment station. The oven currently being used is on loan from another location and will need to be returned at the end of this season. The plant sample drier will be used to dry all the plant samples collected in the growth analysis studies for dry weight determination. Dry weights of leaves, stems, petioles, seeds, and pods are important state variables predicted by the crop models as a function of time and will need to be validated.

8. A digital balance is needed to weigh the dried plant samples and determine dry weight of leaves, stems, petioles, seeds, and pods. (see 7 for further justification).

9. Two backpack motor sprayers will be used to spray the crop model calibration plots at the Jutiapa experiment station and the plots in the farmers' fields with fungicides and pesticides to prevent unnecessary losses due to pests or diseases.

10. The camera will be used to make pictures or slides of the various plots and plants during the regular growing season. Plant observations will be recorded on film in order to be able to verify the actual status of a particular treatment later when the data are being used for model calibration and validation.

11. A seed moisture meter will determine percentage moisture content of the seeds at final harvest; it is an indication of the harvest maturity of the seeds.

12. File cabinets will be used to store records and data collected during the field and socio-economic studies.

13. A desk is needed for the anthropologist, hired by this project, and the agronomist, paid by ICTA.

14. A computer desk is needed for the computer and printer. A special room with an air conditioner will be assigned for computer use at the experiment station in Jutiapa. The ICTA supported data processor, Ms. V. Ibañez, will be entering the data, supervised by Ing. Carlos Heer.

15. The book shelf will be used to store software, manuals and other related computer books and magazines.

16. Transportation is a very high priority item in this project. Because data will be collected over a relative large area, vehicles are needed for the researchers to be able to visit the farmers for surveys or visit the experiments in the farmer's fields. Data collection will be very intensive and therefore one vehicle needs to be assigned permanently to the project supported anthropologist, responsible for collecting the socio-economic data, and one vehicle will be assigned to the ICTA agronomist, Ing. Monterroso, responsible for plant data collection. Because of the poor condition of the paved roads in Guatemala, and the many unpaved roads to small towns or villages, the actual life span of vehicles is not as long as in the US.

17. Gasoline and diesel for the two trucks mentioned in item 16, and for the trucks used by the ICTA breeder, Dr. Masaya. and ICTA socio-economist, Ing. Heer, involved in the project.

18. Maintenance of the new vehicles and for the trucks used by the ICTA breeder, Dr. Masaya, and the ICTA socio-economist, Ing. Heer, involved in the project. Because of the conditions of the roads, more maintenance is required (see 16).

19. Materials include seed, fertilizer, herbicides, pesticides, fungicides, tags, sample bags, and others for conducting the experiments. It is also includes office supplies: paper, pens, etc., and computer supplies: diskettes, and computer paper.

20. Line item allocated for xerox copies, stamps for postage, telephone and telex expenses.

21. One of the objectives of the project is to organize a workshop to demonstrate the models to potential users. Costs will include the rental of microcomputers, printing of handout material, mailing and telephone expenses, and the reimbursements of some participants for room and board if their organization can not support them. It is planned to hold the workshop during the beginning of the third year, which will be in the fall of 1991. The workshop will last between three to five days.

22. Domestic travel expenses will be used to reimburse Dr. Masaya, Ing. Heer, and Ing. Monterroso, and the project supported anthropologist for travel directly related to socio-economic or plant data collection. It is expected that some overnight travel will need to be done by some of the project investigators. Jutiapa is not within

commuting distance of Guatemala City (three hour drive). Dates can not be predetermined because of the uncertainty of the timing of some of the experiments.

23. International travel will mainly be used by the Guatemalan investigators, Dr. Masaya, Ing. Heer, and Ing. Monterroso, to attend the annual meeting of the PCCMCA (Central American Agricultural Organization) to present oral and poster presentations of the results of this study. The PCCMCA is organized once a year during late March or early April in a Central American city.

24. A part-time University of Florida student will receive the crop data collected in the field experiments in Jutiapa, check for errors, and enter the data into the existing Database Management System of DSSAT. After data entry the student will create the input files for the crop models through the data retrieval program, and will do a first calibration or validation of the crop models. The student will also run the weather generator and strategy analysis programs. The student will be supervised by the University of Florida supported crop modelers, Dr. Hoogenboom and Dr. Jones.

25. The major part of the Florida budget is spent for travel between the United States and Guatemala by the University of Florida supported crop modeler, Dr. Hoogenboom, and the University of Edinburgh supported bio-economist, Dr. Thornton, to assist and advise with the data collection procedures. It is also planned that part of the time will be spent with the cooperators on teaching them how to use the already existing software (crop models, DSSAT), and the still to be developed whole-farm model. Several trips will need to made during the length of the project because of the many experiments designed for data collection and the development of the various models. An average trip will probably last between 10 to 14 days and will cost around $ 2,000.00. Five trips are scheduled for the first year (three for the bio-economist, two for the crop modeler), four for the second year (two trips each for the bioeconomist and the crop modeler), and travel for the last year includes the expenses of the bio-economist Dr. Thornton and the crop modeler Dr. Hoogenboom to organize and participate in the workshop.

This proposal has not been submitted to any other sponsor.

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APPENDIX

The Role of Biological Simulation Models in Farming Systems Research

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ABSTRACT

The use of biological computer-based simulation models is considered with reference to Farming Systems Research. Such models have a role to play in the design of appropriate technology packages for poor farmers. The potential benefits for speeding the design process are such as to encourage the finding of solutions to, or the minimisation of the impact of, the severe conceptual problems that exist. Certain characteristics in the design of biological models can be enumerated, which may be expected to facilitate their use in such a process.

INTRODUCTION

Computer simulation models of a level sufficiently detailed to warrant the description 'biological' can be used in various ways once they have been adjudged to be valid. A valid model constitutes a reasonable representation, for the purposes defined by the designer of the system that was modelled. Two broad areas of use might be distinguished. First, a biological model might be used as a component of management information system (Lemmon[12], for example). In such a case, the model would act as an aid to the user in making a decision—for example, when to plant a crop, when to spray for a particular disease, or when to move cattle onto a certain type of pasture. A second broad area of use lies in the research process itself; highly organised information is not necessarily required, and the characteristics o

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the biological component appropriate to management information systems[20] may no longer be suitable.

The distinction, whilst useful, is not absolute; neither is account taken of models which do not fit into such a classification (for example, models constructed for didactic purposes). The purpose of this paper is briefly to inquire into the suitability and potential role of biological models generally within the second of these broad areas of use and specifically in the multi-disciplinary framework of Farming Systems Research (FSR).[17,18] Farming Systems Research provides an ideal backdrop to a theoretical consideration of the role of models, since very different types of investigation are accommodated within its boundaries. The paper proceeds with a short description of FSR, and then describes how biological models might be used within this framework, potentially improving the efficiency of operation of FSR. It is concluded that biological modelling, as well as socio-economic modelling of whole farm systems, within the framework of FSR is both desirable and feasible, although severe conceptual problems remain to be overcome before modelling can be used as a routine methodology for the design of appropriate technology packages and to help overcome the delay between design and adoption on a regional scale.

FARMING SYSTEMS RESEARCH

The translation of research findings into technology packages which can be widely adopted by farming constitutes a major problem in the development of agriculture in many countries. The reasons for the delay between the identification and adoption of technology include the following:

—some applied agricultural research is inappropriate to farmers' needs;
—the risks involved in adopting new technology are not appreciated by researchers;
—farmers' objectives often do not coincide with those assumed by researchers and extension personnel; sometimes, farmers' objectives are not even known;
—farmers experience management problems associated with new technology which are not always foreseen by researchers;
—farmers operate within a set of constraints (resource-related, political and social) that may not be fully appreciated by the researcher.

FSR was developed in an attempt to reduce this delay and to encourage farmers to introduce new technology more quickly. It is difficult to give a precise definition of FSR, owing to the fact that many methodologies, and

thus much terminology, exist. It is perhaps more useful to list the features of what is commonly understood by the term. Following Biggs,[5] some of these are:

—the activities of the farmer are analysed holistically, implying that the approach is inter- and multi-disciplinary;
—the clients of FSR tend to be small farmers, clustered in reasonably homogeneous groups;
—it is essentially downstream, problem-solving research (where the problems should be specified by the farmer);[7,15] feedback from such research can be used to modify upstream research activities;
—it involves surveys and on-farm trials, i.e., farmer participation;
—it is a dynamic process, capable of self-correction.

Four general but sequential phases can be identified: the diagnostic phase, where existing production systems are examined with respect to constraints of all kinds; the design phase, where potential improvements are identified; the testing phase, where promising production possibilities are evaluated under local farmers' conditions; and the extension and monitoring phase, where the package is passed on to more farmers and evaluated further.[3]

In general terms, assessment of experimental findings leads to the testing of a preliminary technology package on a small number of farms in a region. The package might involve a particular cultivar/fertiliser application/disease control program. The results from small-scale plots are monitored, usually over a number of seasons, and the appropriateness of the package may be confirmed in some sense. If so, the package may then be applied on a larger scale on a limited number of farms, not only with the anticipation of again confirming the value of the package, but also now collating farmers' initial reactions and their views on management problems. Eventually, the package may be established at full farm scale on a number of reference farms in the region. Monitoring of the crop and of farmers' reactions takes place. Inevitably, several more seasons must be involved.

A similar procedure could be anticipated for other crop and livestock enterprises before the farming systems researcher can be expected finally to put together a suitable crop rotation and assess yields, their variation, and thus expected profitability of a whole farming system package.

MODELLING AND FSR

The advantage of the approach outlined above is that the technology is assessed in a whole-farm context; interactions between the various farm

activities during the whole course of the year are included in the assessment process. A full appreciation of the resource demands of the farm is possible, and the managerial and social implications for farmers and their families may be judged. Some adaptation or refinement of the technology is almost certain to take place during the testing phase. However, it is clear that time and substantial resources are involved, and that, in addition, no assessment can readily be made of how the package should be modified in different districts, in response to different soils and changing local climates. Again, the bias of traditional FSR has been towards cropping systems, despite the observation that much small-farmer agriculture revolves around the use of animals.[11] The reasons for this bias may be attributable to the complexity and diversity of animal–crop production systems[14] and the many seasons often necessary for testing technology packages involving livestock because of the length of most farm animals' reproductive cycle.

Simulation modelling, in addition to other modelling techniques,[2] has some potential for overcoming such problems, and also in speeding the transition from the design stage to the testing stage and beyond. Specifically, two reasonably distinct roles can be envisaged: the identification of suitable germplasm, and the identification of appropriate management packages, for a particular locality.

Comparatively simple crop models can be used to identify genotypic characteristics that are desirable in a particular situation. Given climate and soil data, genetic 'parameters' can be varied, and the results assessed in terms of the suitability of the hypothetical plant. Such genetic parameters constitute the mechanism whereby different cultivars of a particular crop may be modelled. For example, cultivars of wheat differ in their sensitivity to photoperiod and in the duration, in degree-days, of the juvenile phase, *inter alia*. A situation where desirable genotypic characteristics would need to be identified is exmplified in the linking of a number of models to simulate crop rotations. In parts of the world, the growing season allows two or even three crops to be grown in a year; in such cases, timing and the duration of the crop become crucial to the success of a rotation. Experimentation with the genetic parameters embedded within the relevant crop models could allow the experimenter to say something about the sequence of crop types and cultivars which would allow a productive and stable rotation. A second example is provided by considering the interactions in a tropical grass–legume pasture for animal production. The variation in genetic characteristics of such pasture mixtures is enormous,[6] both under grazing and in its absence. The differential growth rates of the two components in the sward lead to dominance of the one over the other, although this is modified by selective grazing, for example. A biological model which was capable of simulating, at a simple level, the growth of the grass and the legume in

response to selective defoliation by the animal, could speed considerably the long process of testing mixtures in the field for long-term stability and compatibility of growth habit. For instance, a well-adapted grass of only moderate palatability might have a high growth rate. In identifying a suitable companion legume species a balance has to be found between high growth rate, to combat the dominating effects of the grass, and low palatability, which might lead to a pasture of relatively stable composition but might exhibit little benefit in terms of increased energy or protein content of the forage. Stability analysis using the model could result in a genetic blueprint for a suiable companion species, and germplasm collection could then concentrate on attempting to find a well-adapted plant with the requisite characteristics.

The second area where simulation modelling could be of benefit is in the identification of appropriate management packages. It is apparent that there is some overlap with the area considered above. A validated model can be used to determine crop yields under local conditions in response to alternative input packages. Furthermore, such response can be determined over many years of simulated environment; estimates of yield variability can be made, and some measure of risk can be assessed in relation to alternative packages.[16] Comprehensive crop response estimates can thus be obtained quickly in relation to input variables both singly and in combination. The opportunity to develop new technology packages via the model and to explore the impact of seasonal variation on crop productivity presents a flexibility not available to research based on field trials.

Consider again the identification of cropping sequences. There is clearly a large number of combinations of such sequences, even with comparatively few crops. The biological and economic variability of a particular sequence over long periods of time are a function of many things: the dates of sowing, the length and commencement of the growing season (which may be seen as stochastic variables), weather patterns during growth, and ability to harvest close to the optimum time, to name but a few. In addition, the whole sequence has to operate within the resource constraints of the farmer. The response of the crops to different sowing dates can be investigated using simulation experiments. Where the number of feasible alternative crop sequences is large, a two-stage assessment process might be suitable. The preliminary stage would involve the identification of a subset of particularly promising crops sequences, using little or no replication. The variability of this more manageable number of alternatives could then be investigated through the use of a large number of stochastic weather time-series, leading to recommendations involving a small number of crop sequences which exhibit, for instance, relatively high levels of production and marked stability, given local climatic conditions.

ASSOCIATED PROBLEM AREAS

The provision of valid biological models

A suitable crop model for poor farmers will, because of the nature of their production systems, have to take account of the potential impact of pests and diseases, and also of the fact that intercropping is extensively practised in the tropics. The technical problems involved with incorporating these factors are not insurmountable, but the situation is not facilitated by the sheer multiplicity of possibilities and probable data shortages. Ideally, a generic solution is required: it may be that the effects of pests, diseases and intercropping are quantifiable in terms of competition (for example, see Vandermeer[21]). Any discussion of the use of simulation models presupposes that their validity has been demonstrated to some degree. It is thus highly pertinent to consider this presupposition.

A suitable crop model would be required to have some measure of portability between alternative sites. This in itself implies a sound structure based on causal mechanisms, to a large degree. Total portability, whilst a desirable characteristic of a crop model, is not likely to exist, for several reasons:

- —the data from which model parameters are estimated are never measured in a totally specified environment;
- —different segments of a model are usually based on a variety of sources, each one specifying only partially the environment under which it was developed;
- —all parameters and relationships are of necessity obtained under conditions of uncertainty; occasionally, the levels of uncertainty may be very large.

There is thus no guarantee that the best-fit parameters, evaluated from various incompletely specified environments, will result in the best predictive ability when the model is used in any particular (also incompletely specified) environment. The existence of what might be termed residual environmental parameters, which might include climatic variables not specified in experimentation, soil type details not recorded, or unspecified management input, suggests that some measure of fine-tuning or calibration will be required before a model can be used for a particular locality. Such calibration can, however, be carried out in an algorithmic fashion, and it may thus be possible to automate it (see Harrison,[10] for example).

It may be that selective adjustment of key model parameters between narrow, well-defined limits, in an attempt to minimise some function of

discrepancy between model output and real system outputs,[13] is not capable of bringing about satisfactory model performance; alternatively it may be that satisfactory performance can be obtained only by adjusting parameters independently for a number of locations within the same district. In either case, the model is shown to be unsatisfactory, and for validity to be re-established, changes are required in the relationships of the model itself, rather than simply to its parameters. In essence, model calibration should be viewed as a logical requirement when mechanistic models are applied in situations for which they were not specifically built. Indeed, that a model can be calibrated so as to operate in radically different environments is a positive indication of the universality of the functional relationships used in its construction.

The requirement is thus for biological models that are as independent of location as possible, which can be transported to the research site and calibrated and validated for that site using locally generated field data.

Conceptual difficulties

There are several conceptual problems associated with the use of models in the types of research outlined above, even allowing for the existence of valid crop simulators. Among these are the following:

(1) It will usually be unknown what levels of variability inhere in the real system over long periods of time, and how these relate to the variability generated through simulation. For an annual crop, it will often be possible to estimate the suitability of the model's stochasticity by deriving probability density functions of important output variables (such as yield), and then either compare these with records, if they exist, or consult an expert who has long experience of the crop in the area. (In certain cases, simple inspection of a yield distribution function might lead to identification of problems; for example, biological processes tend not to be bimodal, and a suggestion of discreteness, or steps, in the density function of a supposedly continuous variable is indicative of a bad model.) Problems ensue, however, if the crop is new to the area, so that neither experts not records exist, or if 'long-term' technology is being assessed. Thus in the case of complex rotations, or where animal production is an integral part of the system, the variability that exists over long time periods will simply be unknown. It is not clear how it might be possible to deal with this problem; there will rarely be a compelling *a priori* reason for supposing that the rankings, in terms of variability, of a set of production packages will remain unchanged as absolute levels of variability vary. Of course, this is no less a difficulty in traditional FSR; a consideration of the use of models in the research process simply underlines the nature of the problem.

(2) Yield levels obtained on the experimental station are rarely, if ever, obtained in the farmer's field. The reasons for this may be attributed in part to problems in the resource base of the farmer, so that the commercial crop is grown under dissimilar conditions as far as pests, diseases and nutrients are concerned. Problems associated with timeliness (the ability to prepare a decent seed bed or to harvest, for example) are also attributable in part to the resource base of the farmer; then again, such problems are also related to the farmer's perception of the optimum management techniques necessary for a crop. Whatever the causes, it is apparent that the divergence between experimental and commercial yield levels has to be taken into account somehow. It is quite possible that the optimum (in some sense) strategy for yields of the order of magnitude of those obtained on the research station is quite different from the optimum (in the same sense) strategy in a farmer's field. Not all of the possible reasons for the differences in yields are immediately amenable to empirical treatment.

(3) A farmer's field exhibits different soil and climatic attributes from those of the experimental station; in addition, there may exist considerable variation within a field. In essence, this is a problem associated with aggregation: of ascribing homogeneity to systems where it does not really exist. Profound conceptual implications exist as a result, but pragmatism dictates that there is a clear limit to the quantity of information that can be supposed to exist and which can be assimilated in a model. The resolution of a model is essentially a function of the quality of the data used in its construction, so that apparent sensitivity to changes in input data becomes spurious, after a point. In addition, cases will undoubtedly exist in which the biological variability is outweighed by the variability arising from other sources. However, it is recognised that the question of spatial variability on the micro level will go largely unanswered at present.

The socio-economic framework

In the same conceptual manner in which biological models can enhance field experimentation, so suitable models of farming systems incorporating biological and socio-economic components may enhance the procedures of farming systems experiments. A requirement for biological feasibility is not sufficient; rather, it may become necessary to take account of market changes in relation to the supply of products, general price and cost variability, the credit facilities sometimes necessary for bringing about change, prospective adopters' attitude to debt and use of borrowed funds, and the seasonal labour requirements of proposed new systems, to name but a few factors. The biological components in a farming systems model thus have to be sensitive not only to climate and soil types, but also to management practices and farm resource availability.

One potential use of biological models embedded within a socio-economic framework is associated with the *ex ante* assessment of adoption of new technology over large areas. Whilst subject to a familiar set of aggregation difficulties, information could be generated on a regional basis, in relation to a particular technology uptake rate or, more realistically, to a probability distribution of attitudes to adoption,[19] and this could provide useful input to studies designed to assess the impact of new technology in particular areas. Ultimately, alternative options for the development of farm and district facilities could be superimposed: for example, policies for improving the availability of seasonal and long-term credit to poor farmers, and the development of nearby markets and the transport systems necessary to reach those markets. (The difficulties involved in monitoring the spread of technology and in the *ex post* assessment of the benefits for farmers and society in general, have been much discussed.[1,5,9])

Although this would appear to be the logical extension in the application of biological models, little idea is given of the enormous increases in complexity that follows as a result of combining a number of modules capable of reacting automatically to external and self-generated stimuli. In particular, the definition of the socio-economic framework within which the farmer operates presents problems. As Anderson[1] notes, it will usually be expedient to sidestep the issue of what society as a whole, and not just the farming sector, regards as being desirable and concentrate on the goals and objectives of farm families, whilst recognising that there will be times when the goals of other sections of society simply cannot be ignored. Even if the framework is restricted to the farm family, there are problems in trying to elicit what will inevitably be multi-attribute preference functions.[1] The building of a whole farm model requires that decision making in a constraint-ridden production system can be represented in some algorithmic way (see the models of Chien and Bradford,[8] or Beck and Dent,[4] for instance). Such assumptions are justified in part by the consideration that there is little else that can be done if the problem is to be attacked at all, and that it is better to use an inaccurate but internally-consistent framework than a woefully inadequate one. The practical problems of measurement remain.

CONCLUDING REMARKS

It is apparent, from the considerations above, that certain types of biological model are better associated with the research process than others. Three characteristics can be enumerated. First, a model capable of calibration is likely to be mechanistic as distinct from empirical. In situations in which the researcher is dealing with an untried or hypothetical crop, a mechanistic model is a prerequisite; indeed, the empirical performance of the

relationships may be of secondary importance compared with the ability of such relationships to react in a causally reasonable fashion. By the same token, there is no basis for judging the predictive power of an essentially empirical model in the situation in which crop phenotype data, or other relevant information, do not exist. Second, it follows that, for similar reasons, it should be possible to investigate the effects of changes in genetic parameters. Genetic parameters either should be included explicitly, or it should be possible to isolate their effects on important relationships in the model in a straightforward fashion. Third, the level of detail in such a model should be high, since it may often be required to resolve between similar production possibilities on similar soils. This implies some sensitivity to climate, soil, water and nutrient conditions, which in turn implies a certain minimum level of detail.

As documented above, difficulties exist which need to be overcome or effectively side-stepped before whole farm models can be operated within their relevant socio-economic framework. The flexibility offered in the design process, however, and the speed with which technology packages can be assessed, are such as to encourage the finding of solutions to these problems. Through more efficient design, it may reasonably be hoped that the testing stage of such packages is thereby shortened, since the complete package should be better adapted to the prevailing conditions. Biological simulation models have the potential whereby the technology of crop production and the improvements to it by way of appropriate packages can be assessed against the overall framework required for improving the lot of the small farmer. It is likely that significant benefits arise from even the partial application of Farming Systems Research,[1] such as increased communication horizontally and vertically in research communities, and sharper focusing on real problems at the farm level with concomitant feedback to upstream research. Careful application of suitable models can play an important role in promulgating such benefits.

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A COMPUTER MODEL FOR THE SIMULATION OF BEAN GROWTH AND DEVELOPMENT [1,2]

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INTRODUCTION

The main objective of the IBSNAT project is to develop a methodology for planning agricultural development and controlling farming outcomes in the developing countries. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project is a program sponsored by the U. S. Agency for International Development, and is establishing a network of international collaborators, both in the developing and developed countries. The main purpose of IBSNAT is to develop new methods for the transfer of agroproduction technology from its site of origin to new locations with similar or different environments and management practices. The final goal of the IBSNAT project is to integrate new or alternative crops, cultivars, products, and practices into existing farming systems, thereby helping the farmers to make their crops more productive.

To be able to accomplish these objectives the latest systems analysis, crop modeling and simulation techniques are being used. Crop, soil and weather simulation models are being adapted to evaluate a wide range of crop production practices. Management strategies are then developed suitable for soil, weather, and farming conditions at sites where the technology has not yet been tested. Such analysis will help determine the transferability of newly developed agricultural technologies to these sites. IBSNAT, therefore, is developing an easy-to-use, computerized Decision Support System for Agrotechnology Transfer (DSSAT; Jones, 1986). The components of DSSAT include crop models, appropriate data files, a data management system, expert systems, risk analysis procedures, and computer programs to link components and provide specific outputs for users. Crop models are currently being developed for maize (Jones and Kiniry, 1986), wheat, rice, barley, and millet (CERES models), soybean (Jones et al., 1988), peanut (Boote et al., 1988), and dry bean (SOYGRO models), and sorghum, cassava, taro, and potato (IBSNAT project, 1985). With the capability to predict the effects of a wide range of management strategies for several crops, soils, and climate conditions, scientists will be able to design experiments more effectively and evaluate alternate

technologies in less time and for less money. At the same time it can be used to help government agencies to undertake long-term, strategic planning and farmers to make day-to-day tactical decisions (IBSNAT project, 1986).

In this chapter we will discuss the development of a computer model (BEANGRO) which simulates growth of dry bean or common bean (Phaseolus vulgaris L.). Dry bean is one of the major crops in South and Central America and Africa and therefore is one of the crops for which IBSNAT is developing these technologies. The dry bean model BEANGRO will be part of the final version of DSSAT.

MODEL DEVELOPMENT

Both dry bean and soybean (Glycine max [Merr.] L.) are leguminous crops. Because of the similarities in vegetative and reproductive growth stages of these two crops, the basic structure of a model which predicts growth, development, and yield of soybean (Wilkerson et al., 1983, 1985) was used as a basis for the development of a dry bean model (Hoogenboom et al., 1986). Relationships which describe vegetative and reproductive development as a function of temperature and daylength were modified, based upon data published in the literature (Wallace, 1985) and experimental data. Parameters which describe growth and biomass partitioning were changed to fit the characteristics of dry bean (White, 1981).

During model development two field studies were conducted at Gainesville, Florida, to collect intensive growth analysis data for development and calibration of the model (Mahamadou et al., 1987). Canopy photosynthesis was measured for well-watered treatments to relate canopy photosynthetic rates to leaf area index (LAI) and age of the crop (Hoogenboom et al., 1988B). Root length density profiles were taken to determine the rooting profile of dry bean under different irrigation management treatments (Hoogenboom et al., 1988A). Both the canopy photosynthesis and rooting information will be integrated into the current version of the model. Because of the variation in growth

characteristics among dry bean cultivars, initial development of the model was concentrated on two cultivars : "Porrillo Sintetico" and "BAT-477". The same cultivars, together with others, were also studied in trials at CIAT for validation of the model at other sites.

The model was calibrated using data collected from well-watered treatments of "Porrillo Sintetico" and "BAT-477". After initial development and calibration, model predictions were compared with data collected at CIAT for well-watered treatments of 1985 and 1986. Modifications were made in the model to be able to predict start of flowering and physiological maturity correctly at both sites. Minor corrections were also made in the functions which describe biomass partitioning, and pod and seed growth. After the model was able to predict growth and development fairly accurately at both sites, the model was validated for response to drought stress and irrigation management conditions, against data collected in the 1986 Gainesville experiment (Mahamadou et al., 1987).

Future work on the model is still continuing and currently the authors are finalizing a version 1.0 of BEANGRO for distribution to collaborators [4]. A user's guide and technical documentation are also being prepared (Hoogenboom et al., 1988C).

MODEL DESCRIPTION

The dry bean crop model BEANGRO V1.0 predicts dry matter production, reproductive development, and final yield of dry bean for the entire growing season. The model starts at planting and predicts germination of the seeds and emergence of the shoot. It also has the option to initiate the water balance section several days before

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[4] Copies of the dry bean simulation model BEANGRO V1.0 can be obtained by sending four 5 1/4 inch diskettes (356 K) or one 5 1/4 inch diskette (1.2 M) and a letter stating your intended applications to Gerrit Hoogenboom, Department of Agricultural Engineering, University of Florida, Gainesville, Fl 32611, U.S.A.

planting to calculate water movement within the soil profile and soil evaporation based upon rainfall or pre-planting irrigation during land preparation. Following germination, biomass growth is initiated, and leaf, stem, and root tissues are formed. Total canopy photosynthesis is calculated as a function of daily total radiation, LAI, and available nitrogen in the canopy. Maintenance and growth respiration are computed, and subtracted from the gross photosynthetic rate and finally growth of the different organs is determined. All calculations of growth are based on a daily time step.

Depending on the genetic characteristics of a cultivar and the environmental conditions in the form of daylength (or length of the dark period) and temperature, the model predicts flower initiation, start of anthesis, pod set, pod filling and seed formation, physiological maturity, and time of harvest. During the reproductive growth phase flowers are initiated, which then set, form pods and fill with seeds. All flowers which start anthesis on the same day are kept together as one cluster in the model and for all following days the status of each cluster in terms of age, number of pods and seeds, and maturity is updated. Biomass partitioning to roots, stems, leaves, pods, and seeds is dynamic and is based upon the reproductive growth stage of the plant, total amount of soluble carbohydrates available, the plant's drought stress status, other stress conditions, and the environmental factors like temperature, photoperiod and total radiation.

The soil section of the model is described by a one-dimensional profile, and depends on the number of horizons in the soil. For each horizon a saturated water content, a drained upper limit or field capacity, and a lower limit or wilting point are defined. Saturated and unsaturated flow between each layer is calculated and for each layer soil water content as a function of depth is predicted (Ritchie, 1985). Depending on the total amount of biomass allocated to the root system, a certain amount of root length is formed in each horizon. Root elongation is also controlled by the water status of each layer and the layer's relative rooting potential. Total amount of water taken up by the root system is compared to water lost by transpiration

and actual transpiration is the minimum of the two. The climatic potential evapotranspiration rate is predicted based upon temperature and radiation, using the equilibrium evapotranspiration rate as described by Priestly and Taylor (1972).

MODEL INPUT AND OUTPUT

To successfully run the model, a minimum set of input data is needed. IBSNAT has defined a so-called minimum data set (MDS) for systems analysis and crop simulation (IBSNAT project, 1988). Daily weather data, including daily total solar radiation, maximum and minimum air temperature, and daily total rainfall are driving functions for calculation of most of the growth and development sections of the model. A description of the soil at which the experiment was conducted is needed, and it should include a drained upper limit, a lower limit, and a saturated soil water content for each horizon. A relative rooting function is used to describe the rooting profile within this horizon. The calculation of the soil related parameters is very important, especially if a drought stress was observed during the experimental period or if the model will be used to determine irrigation management strategies. Management related variables are needed to define row spacing, plant spacing, planting density, planting date, and irrigation type, dates, and amounts. Finally the cultivars used in the experiment have to be identified. A detailed description of all the input files for the crop models is found in IBSNAT Technical Report 5 (IBSNAT project, 1986B).

During the actual model run and execution period, phenological growth stages and biomass of various plant parts are estimated. To verify that the predicted results are accurate, experimental data are needed for comparison. Detailed information about the required and requested field variables is given in IBSNAT Technical Document 1 (IBSNAT project, 1988). Seed yield, total number of seeds, and seed size need to be measured at harvest time. Start of flowering and physiological maturity also have to be recorded. However, further

information about other vegetative and reproductive growth stages is required to be able to define a correct set of parameters for new cultivars. Growth analysis samples, in which leaf, stem, pod, and seed weight and LAI are collected can be used to define the parameters involved in biomass partitioning and to verify that the model's biomass predictions are correct. Especially when the model is used to predict growth and yield of a new cultivar initial information is needed to define the photoperiod and temperature sensitivity of that cultivar. Once the model has been calibrated for a particular set of environmental conditions, less data are needed for further validation of the model. In some cases, together with the required weather, soil, and management data, only final yield can be used to verify the model predictions.

RESULTS

Gainesville

For initial development of the model, a water management study was conducted at the University of Florida Research and Education Irrigation Park during the 1986 Spring season. Beans were planted on March 25 at a row spacing of 0.61 m and a planting density of 32 plants m^{-2}. The soil at the experimental site was a Millhopper fine sand (Loamy, siliceous hyperthermic Grossarenic Paleudults). Two cultivars were used in this study : "Porrillo Sintetico", a small, black-seeded type bean with a light sensitivity to photoperiod (group 3, CIAT notation), and "BAT-477", a small, cream-seeded type bean with only a very slight sensitivity to photoperiod (group 1, CIAT notation). Five different water management treatment were applied, ranging from daily irrigation to rainfed and non-irrigated (Mahamadou et al., 1987). For calibration of the model only the data collected in the well-watered treatments were compared wit model predictions.

In Table 1 a summary is shown of the inputs values and parameters which initialize the model. In the same table also a detailed

description is given of the soil profile and the soil water contents at the lower limit, drained upper limit, and at saturation. At planting the total amount of extractable water in this profile was 135 mm. Maximum rooting depth was based upon field measured data (Hoogenboom et al., 1988A).

Maximum and minimum air temperature, daily total solar radiation (RAD), and length of the daily light during the growing season are shown in Fig. 1A, B and C, respectively. Accumulative rainfall and irrigation are presented in Fig. 1D. Temperature, radiation, rainfall, and irrigation are all actually measured data during the growing season and are used as input or driving functions for the weather variables.

After reading the values for the input functions, the model predicts a vegetative and reproductive growth stage, total biomass, LAI, and soil water balance components in the form of evaporation, transpiration, and evapotranspiration (Table 2). Because of low night temperatures early in the season (fig. 4A) plants did not emergence until 9 days after planting. Start of flowering was predicted at 47 days after planting and physiological maturity at 91 days after planting. Total evapotranspiration during the entire growing season was 424 mm, while total irrigation and rainfall were 549 mm and 181 mm respectively (Fig. 1D). Some drought stress was predicted by the model as indicated by the values for turgor stress (Table 2).

A comparison between predicted and field measured values for some of the most important variables is shown in Table 3. Flowering was predicted one day early, while maturity was 10 days late compared with the field measured data. Seed yield was overpredicted by 270 kg/ha and total biomass at harvest by 190 kg/ha. The predicted apparent harvest index was very similar to the harvest index calculated from the field data.

CIAT

The model showed similar predictions using input conditions from CIAT (Table 4). Minimum and maximum temperature, daily total

radiation, length of the daily light period, and total rainfall and irrigation are shown in fig. 2. When fig. 1 and 2 are compared, the difference in environmental conditions between Gainesville (latitude 29.6 ^{o}) and CIAT (latitude 3.3 ^{o}) can be observed. Maximum and minimum air temperature are fairly constant at CIAT while they change as a function of day of the year in Gainesville. Daylength at CIAT is also almost constant, varying between 11.5 and 12 h, while at Gainesville the photoperiod changes from short day to long day conditions.

In an experiment at CIAT beans were planted on September 26 and flowering was predicted 35 days after planting, one day earlier than the field measured value (Table 4). Physiological maturity was predicted 67 days after planting, which was 6 days early compared with the measured data. Total seed yield was 230 kg/ha too low and total biomass was 1000 kg/ha too low, and as results the apparent harvest index was too high. The soil in this experiment was a silty clay (loamy clayey, typic Pellustert) with a high water holding capacity. Because of significant amounts of rainfall at CIAT hardly any additional irrigation was applied (fig. 2D).

Predicted and Measured Growth

Biomass predictions as a function of time are shown in fig. 3. The continuous lines are model predictions, while the circles and squares depict field measured data collected in growth analysis samples. For CIAT the values of all replications are shown (fig. 3b), while for Gainesville only the average value is given (fig. 3a). In general the model predicts total canopy (CANOPY), leaf (LEAF), stem (STEM), root (ROOT), pod (POD), and seed (SEED) weight too low for the experiment at Gainesville, while the predictions for CIAT are within the range of the field data. The model shows similar trends for predictions of seed number (SEED) and pod number (POD, fig. 4).

Although root length density is very difficult to measure for each horizon as a function of the time, the model predicts root length as a function of depth (fig. 5) to give an indication of root growth. For

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Gainesville the root length density in general was higher in all layers, although both soils had the same initial root distribution. However, the silty clay soil has a much higher water holding capacity and therefore needs a smaller root system to extract the same amount of water than the fine sand. At the same time rainfall in the Gainesville experiment was very small, although the experiment was irrigated (fig. 1d). Both the difference in water holding capacity and rainfall therefore caused the difference in root length density distribution between the two experiments.

LAI and specific leaf area (SLA) are shown for both experiments on the same graphs as a function of days after planting in fig 6. At CIAT, leaf area development is very fast and reaches a maximum at 40 days after planting at a much higher value than in Gainesville. Under the environmental conditions of CIAT the leaves have a higher SLA and are thinner than under Gainesville experimental conditions (fig. 6B). This could be caused by lower light levels (fig. 1 and 2) and different day and night temperatures (fig. 1 and 2) at CIAT compared with Gainesville.

The model showed similar predictions for "BAT-477" at both Gainesville and CIAT. Because "BAT-477" only has a very small sensitivity to photoperiod, the model predicted start of flowering and physiological maturity more accurate than for "Porrillo Sintetico". Comparisons between measured and predicted yield and biomass showed the same variation for both "BAT-477" and "Porrillo Sintetico".

Other variables predicted by the model are vegetative growth stage, percentage nitrogen in the canopy, shelling percentage of the pods, and soil water content in the different soil layers. However, in most cases no field data are available for these variables and therefore only the estimates by the model can be shown.

CONCLUSION

The variables discussed in this paper give a representation of the most important ones predicted by the model. Sometimes no field

data are available and no comparison can be made between predicted and measured data. The variables presented in the tables and figures show that for development and calibration of a model detailed field measured data are needed. The variables discussed in Tables 3 and 4 only give an indication of the accuracy of the model, compared with all the information shown in fig. 3-6. However, after one is confident that the model is accurate in predicting several data sets, less information is needed for further validation of the model. During this stage variables presented in Table 3 and 4, e.g. flowering and maturity date, and total seed yield and biomass, are the most important ones which need to be measured.

The data presented in this paper also show that the model is able to predict growth fairly accurately for environmental conditions at Gainesville and Cali, Colombia. However, further development of the model is needed to enhance the accuracy of the model for these two sites. At the same time more data are needed from other locations to verify the predictions of the dry bean model BEANGRO for new sets of environmental conditions.

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Q6.

TABLES

Table 1. Input summary for a simulation of "Porrillo Sintetico" at Gainesville, 1986 under fully irrigated conditions.

BEANGRO V1.0

INPUT SUMMARY RUN NO. 1 SIMULATION BEGINS : MAR 25

INST_ID: UF SITE_ID: GA EXPT_NO: 01 YEAR: 1986 TRT_NO: 1
EXPERIMENT : 2 CULTIVARS, 5 IRRIGATION TREATMENTS
TREATMENT : PORRILLO SINTETICO DAILY IRRIGATION
WEATHER SET : GAINESVILLE, FLORIDA, USA 1986
VARIETY : Porrillo Sintetico PHOTOPERIOD GROUP : 3
IRRIGATION : ACCORDING TO THE FIELD SCHEDULE
PLANTING DATE: MAR 25 PLANTS/M2: 32.29 ROW SPACING: .610m PLANT SPACING: .051m

SOIL PROFILE DATA Millhopper Fine Sand (Loamy,silic,hyperth Gross. Paleudults)
SOIL ALBEDO : .18 U: .0 SWCON: .64 CURVE NO.: 60.0 PHFAC3: .84

DEPTH-m	LL	DUL	SAT	EXTR	INIT	ROOT	SWCN
.00- .05	.045	.110	.230	.065	.110	1.000	.000
.05- .15	.045	.110	.230	.065	.110	1.000	.000
.15- .30	.045	.110	.230	.065	.110	.250	.000
.30- .60	.045	.110	.230	.065	.110	.250	.000
.60- .90	.045	.110	.230	.065	.110	.050	.000
.90- 1.20	.045	.110	.230	.065	.110	.050	.000
1.20- 1.50	.045	.110	.230	.065	.110	.000	.000
1.50- 1.80	.045	.170	.300	.125	.170	.000	.000
SUM mm	81.0	216.0	435.0	135.0	216.0		

Table 2. Output summary for a simulation of "Porrillo Sintetico" at Gainesville, 1986 under fully irrigated conditions.

RUN NO. 1 SIMULATION OUTPUT

UF GA 1986 GAINESVILLE 86

DATE	CROP AGE	GROWTH STAGE	BIOMASS KG/HA	LAI	V-STAGE	WATER BALANCE COMPONENTS ES mm	EP mm	ET mm	RAIN mm	IRRIG mm	DROUGHT STRESS PHOTO	TURGOR
MAR 25	0	SOWING	0.	.00	.0	2.	0.	2.	0.	0.	.000	.000
APR 3	9	EMERGENCE	14.	.03	.1	21.	0.	21.	0.	27.	.000	.000
APR 7	13	UNIFOLIOL.	27.	.06	1.2	28.	1.	29.	0.	39.	.000	.000
APR 9	15	END JUVEN.	40.	.09	1.8	32.	1.	34.	0.	50.	.000	.000
APR 27	33	FLOWER IND	453.	.62	5.0	68.	29.	97.	16.	117.	.000	.142
MAY 11	47	FLOWERING	1614.	2.65	8.7	95.	83.	178.	16.	267.	.000	.062
MAY 18	54	FIRST POD	2651.	4.18	10.7	100.	117.	218.	16.	339.	.000	.001
MAY 22	58	FULL POD	3266.	4.78	11.9	102.	136.	238.	41.	359.	.000	.000
MAY 28	64	END LEAF	4110.	4.82	13.5	106.	177.	283.	41.	420.	.000	.039
MAY 29	65	END POD	4236.	4.74	13.5	106.	184.	290.	41.	431.	.000	.005
JUN 19	86	PHYS. MAT	6756.	3.71	13.5	119.	280.	399.	177.	549.	.000	.006
JUN 24	91	HARV. MAT	5927.	.90	13.5	123.	300.	424.	181.	549.	.036	.110

Table 3. A comparison between predicted variables by the model and field observed data for a simulation of "Porrillo Sintetico" at Gainesville, 1986 under fully irrigated conditions.

RUN NO. 1

UF GA 1986 GAINESVILLE 86

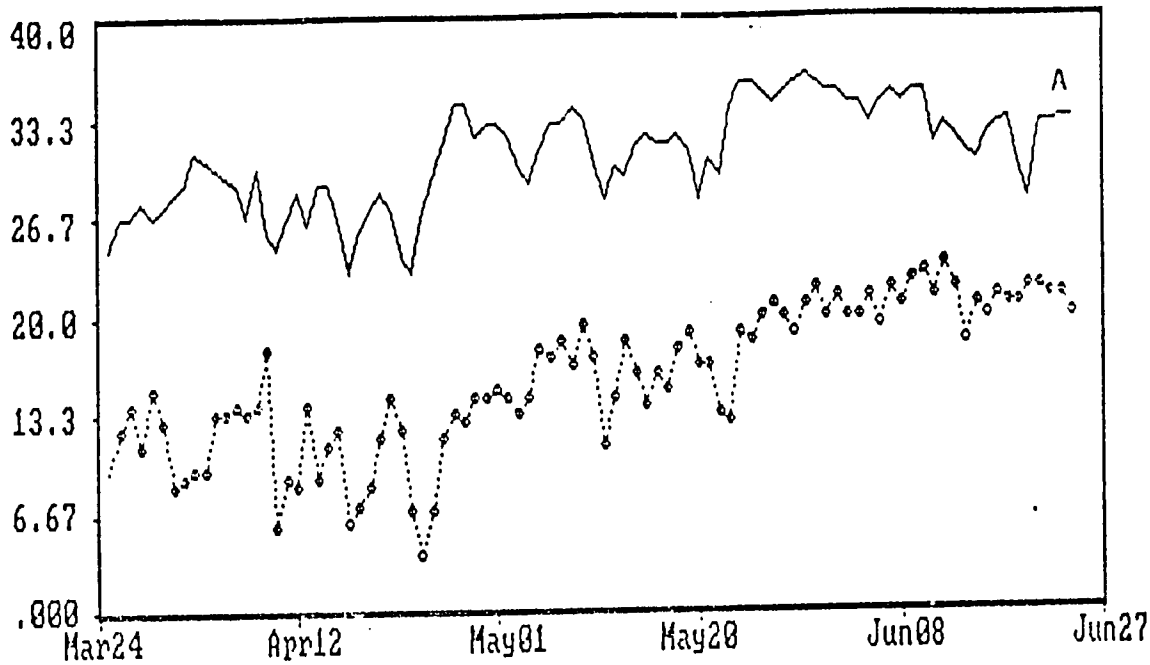
	PREDICTED	MEASURED
FLOWERING DATE	131	132
FIRST POD	138	136
FULL POD	142	144
PHYSIOL. MATURITY	170	160
POD YLD (KG/HA)	4030.00	3605.00
SEED YLD (KG/HA)	2940.00	2667.00
SHELLING PERCENTAGE	72.95	73.98
WT. PER SEED (G)	.221	.166
SEED NUMBER (SEED/M2)	1332.00	1458.00
SEEDS/POD	6.00	5.00
MAXIMUM LAI	4.92	4.93
BIOMASS (KG/HA) AT R8	5920.00	5737.00
STALK (KG/HA) AT R8	1590.00	1252.00
HARVEST INDEX	.497	.465

Table 4. A comparison between predicted variables by the model and field observed data for a simulation of "Porrillo Sintetico" at CIAT, Colombia, 1986.

RUN NO. 2

CC PA 1986 CIAT 86

	PREDICTED	MEASURED
FLOWERING DATE	304	305
FIRST POD	309	0
FULL POD	313	0
PHYSIOL. MATURITY	336	342
POD YLD (KG/HA)	4530.00	4747.00
SEED YLD (KG/HA)	3460.00	3692.00
SHELLING PERCENTAGE	76.38	77.78
WT. PER SEED (G)	.210	.177
SEED NUMBER (SEED/M2)	1651.00	2086.00
SEEDS/POD	6.00	6.24
MAXIMUM LAI	6.43	6.82
BIOMASS (KG/HA) AT R8	6250.00	7326.00
STALK (KG/HA) AT R8	1430.00	1881.00
HARVEST INDEX	.554	.504



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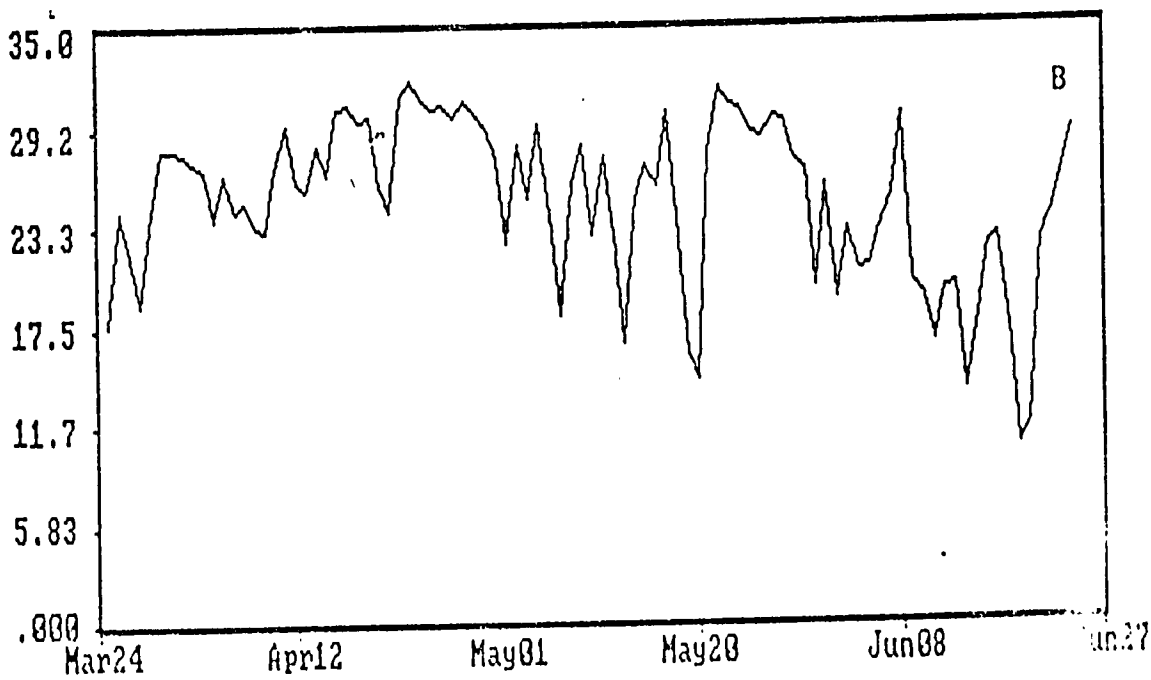
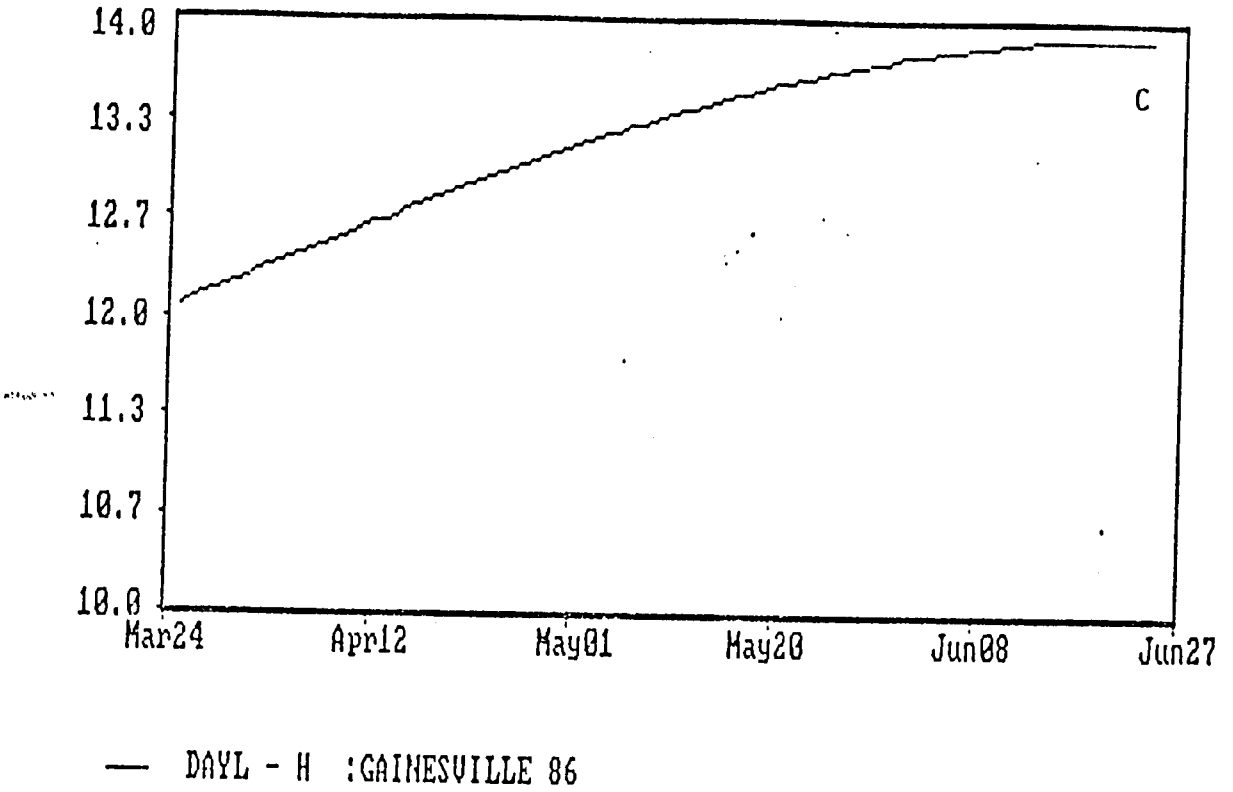
— MAX T - C :GAINESVILLE 86



— RAD - MJ :GAINESVILLE 86



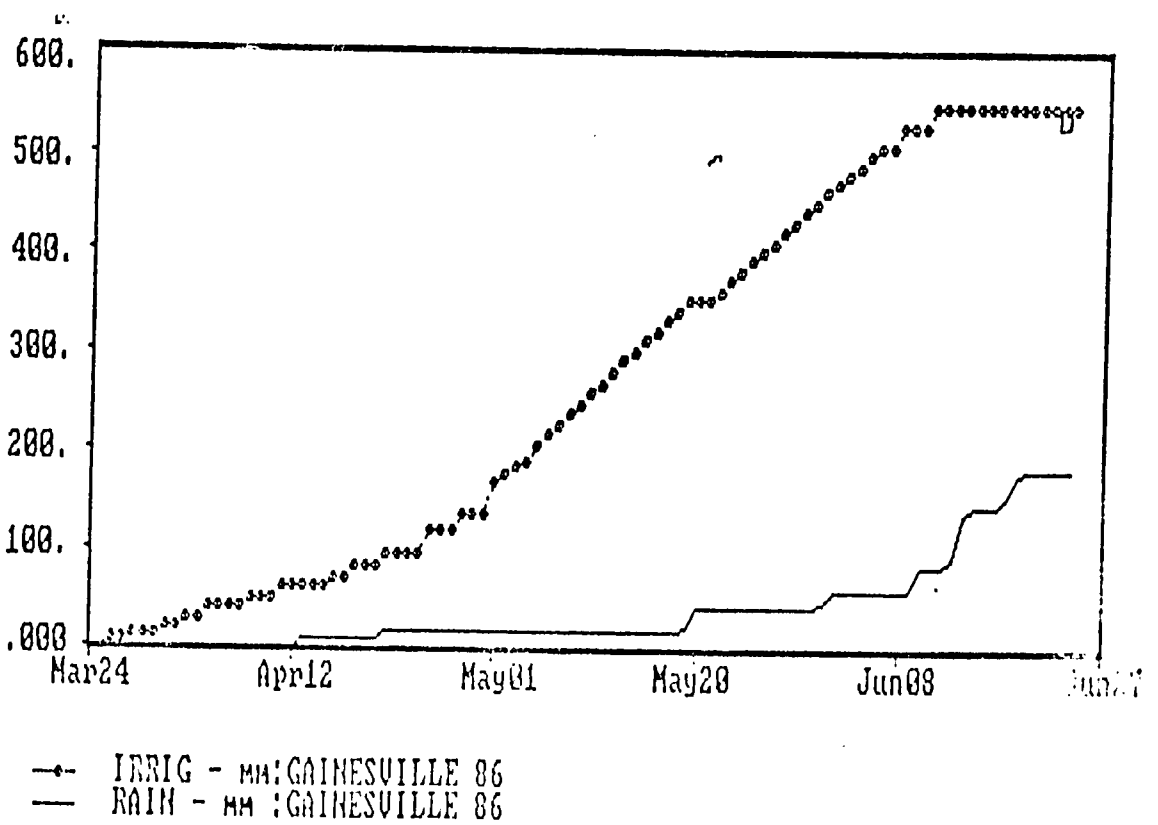
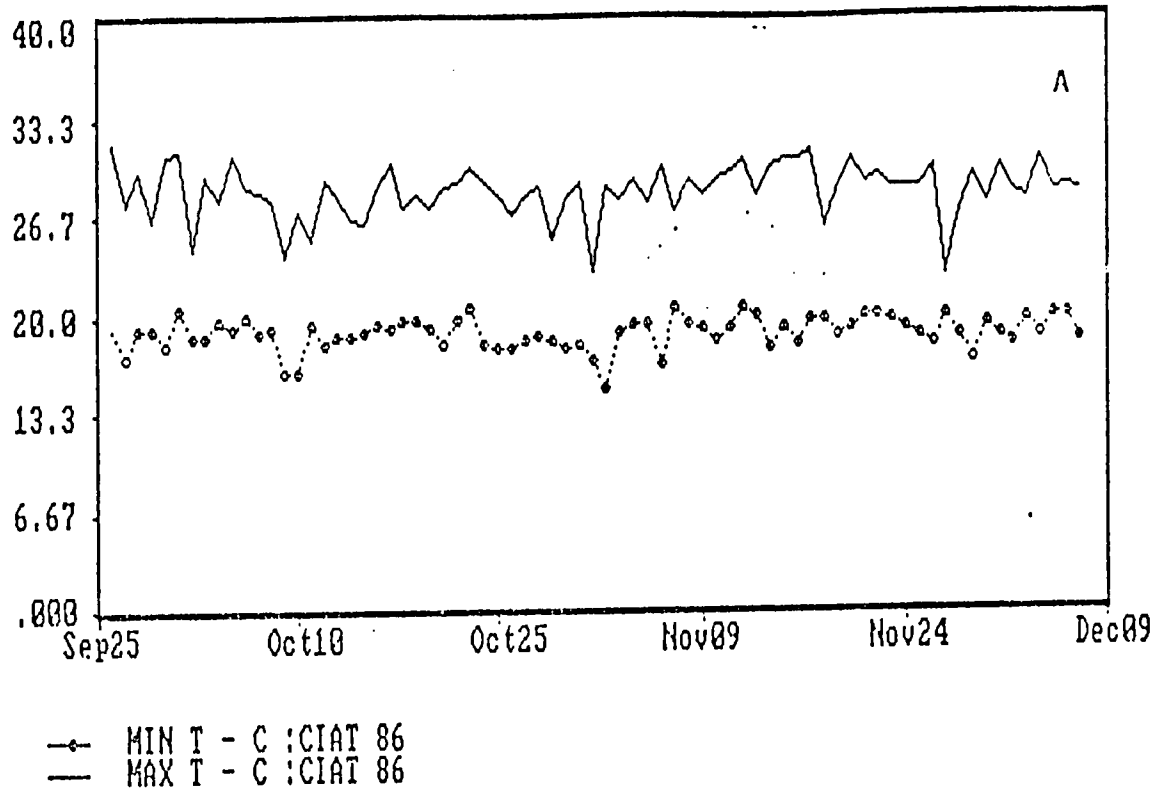


Figure 1. Measured daily maximum and minimum air temperature (A), radiation (B), daylength (C), and rainfall and irrigation (D) at Gainesville, Florida during the 1986 spring growing season.


40.0
33.3
26.7
20.0
13.3
6.67
.000
A
Sep25
Oct10
Oct25
Nov09
Nov24
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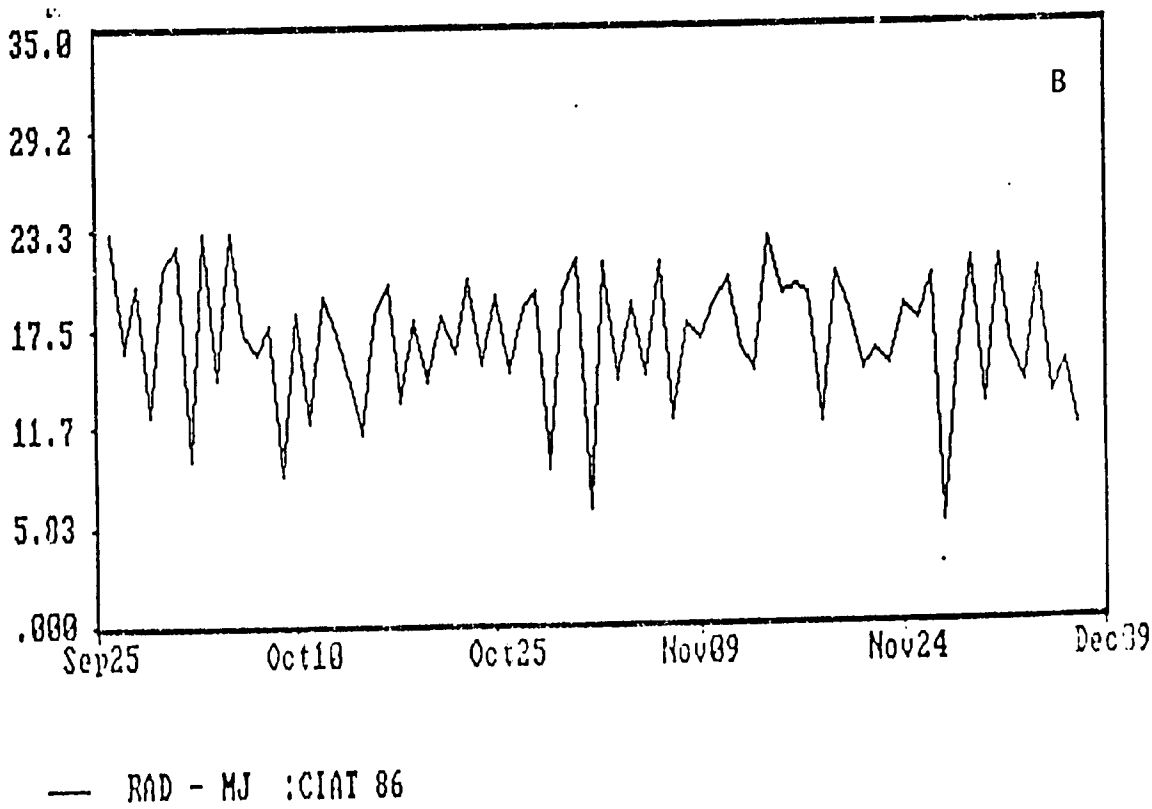
MIN T - C :CIAT 86
MAX T - C :CIAT 86


35.0
29.2
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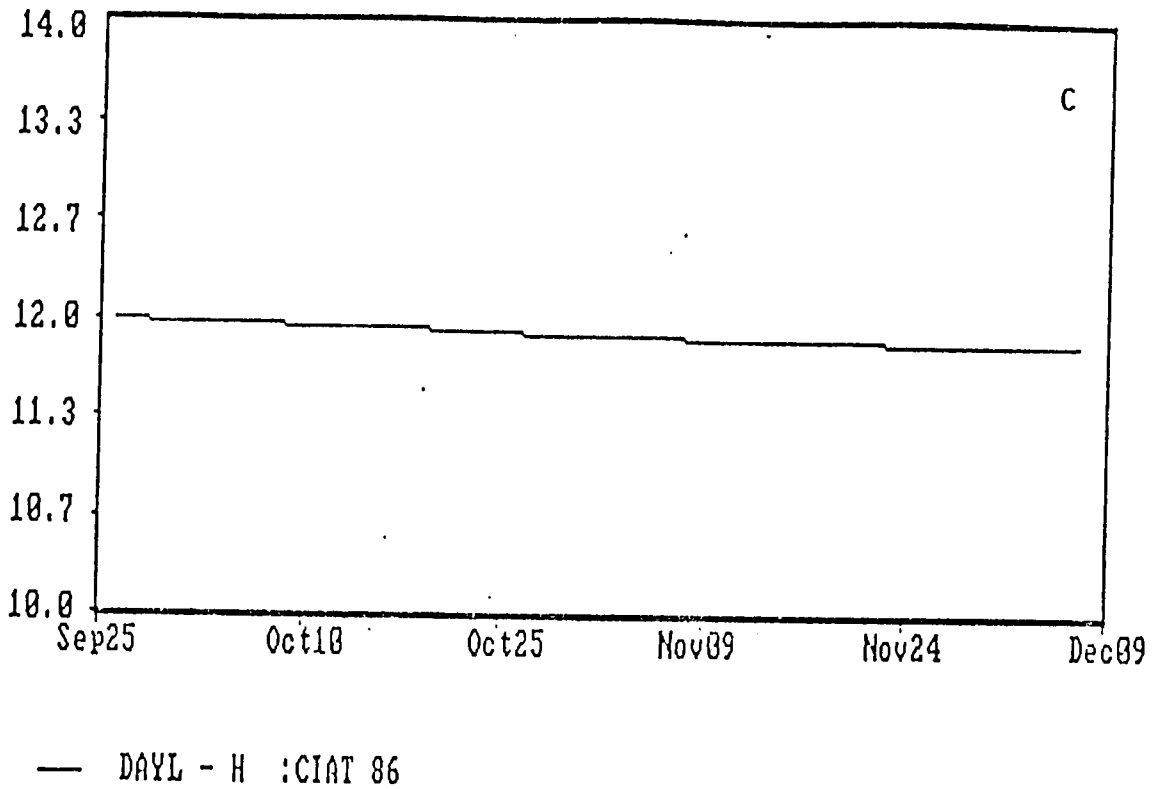
RAD - MJ :CIAT 86



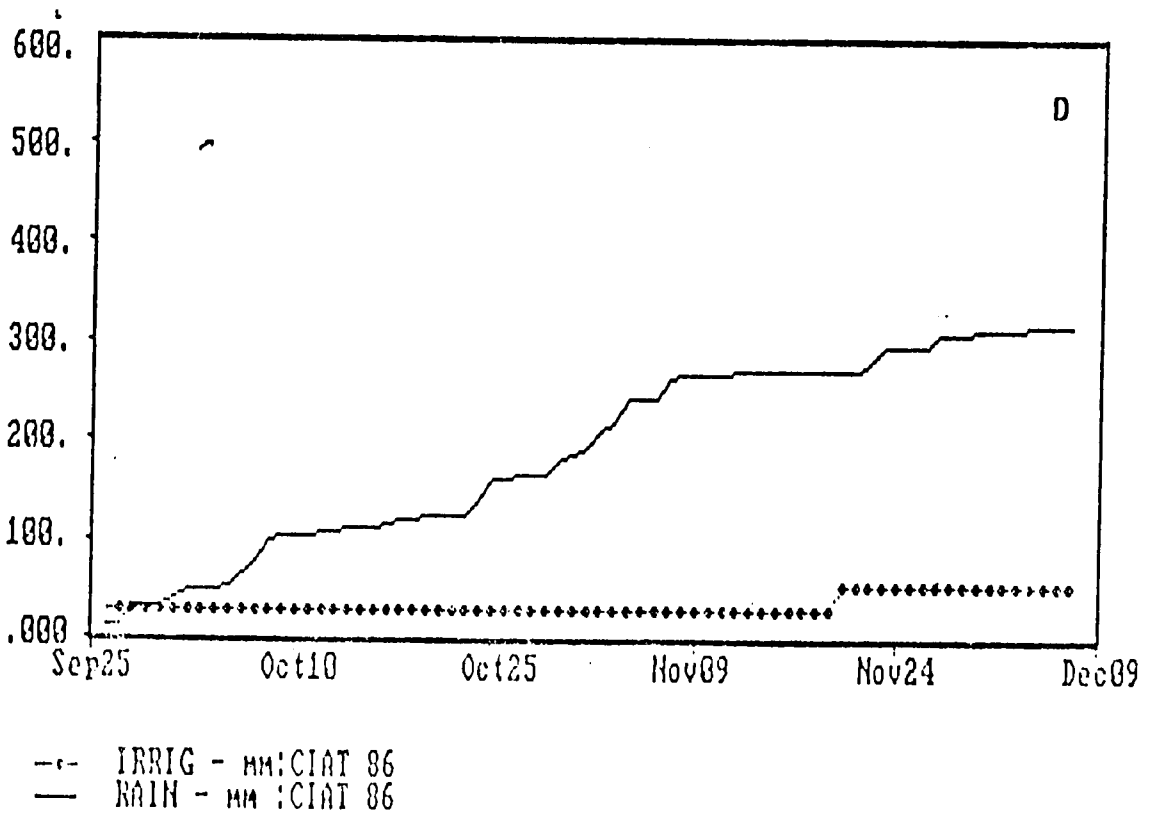


Figure 2. Measured daily maximum and minimum air temperature (A), radiation (B), daylength (C), and rainfall and irrigation (D) at CIAT, Colombia during the 1986 fall growing season.

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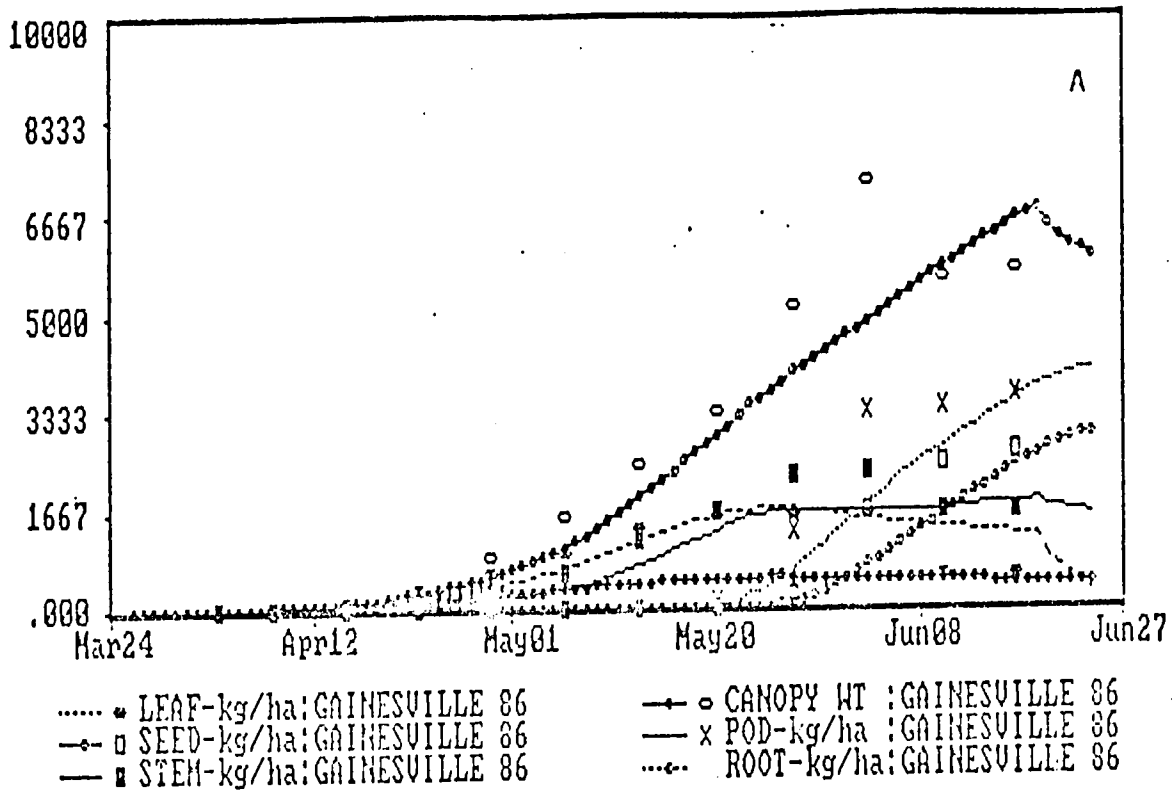


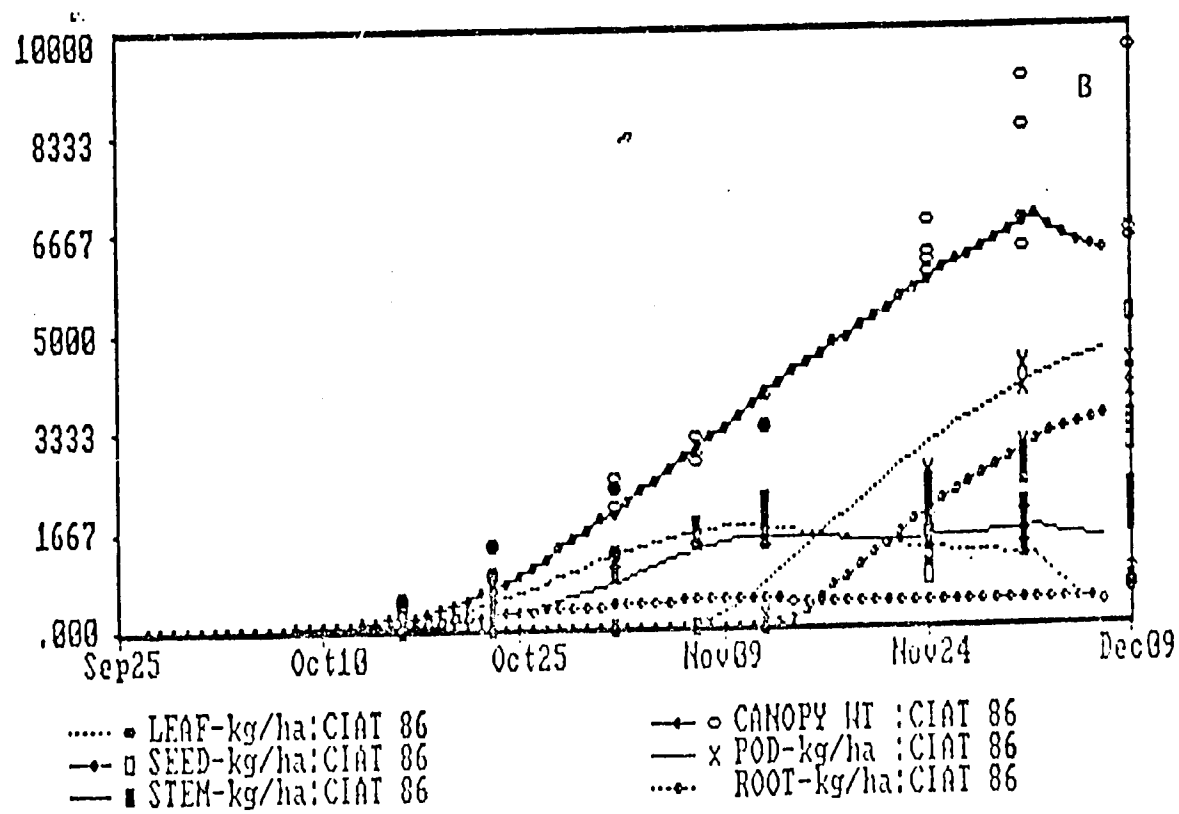
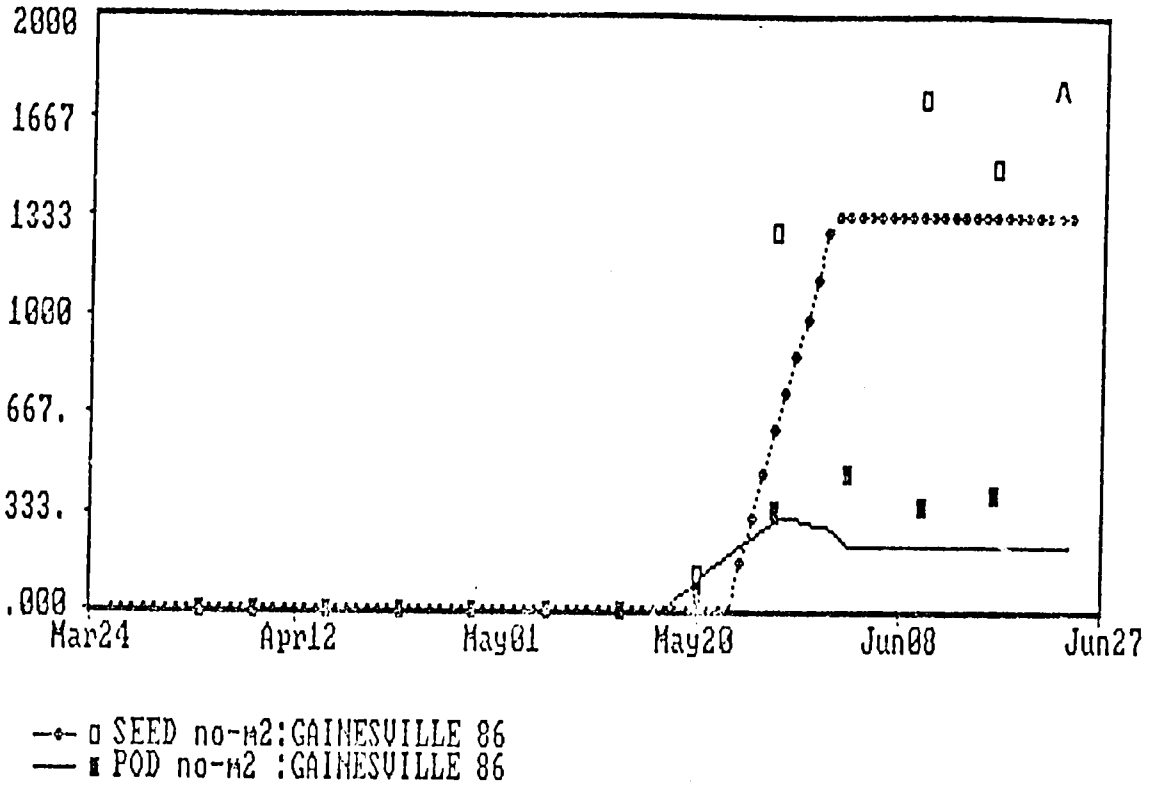


Figure 3. Predicted (*lines*) and measured (*symbols*) leaf, stem, canopy, root, pod and seed dryweight for "Porrillo Sintetico" at Gainesville (A) and CIAT (B).



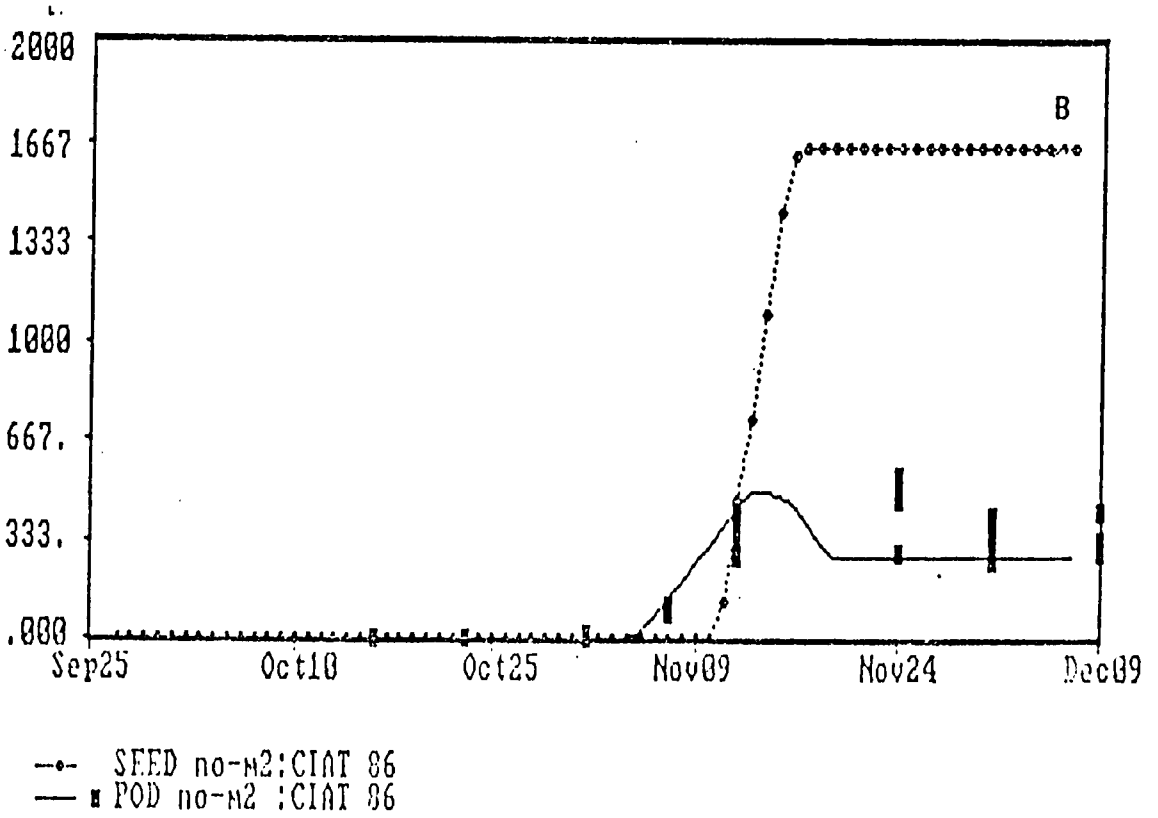
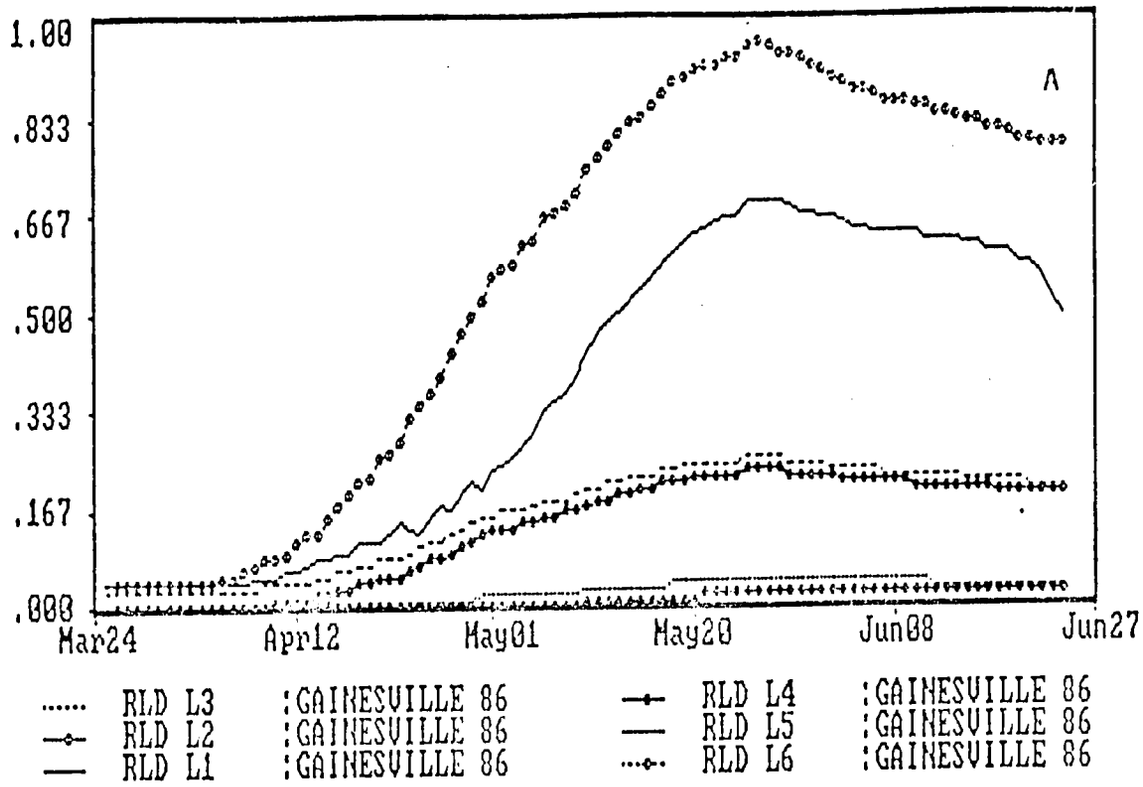


Figure 4. Predicted (*lines*) and measured (*symbols*) pod and seed number for "Porrillo Sintetico" at Gainesville (A) and CIAT (B).



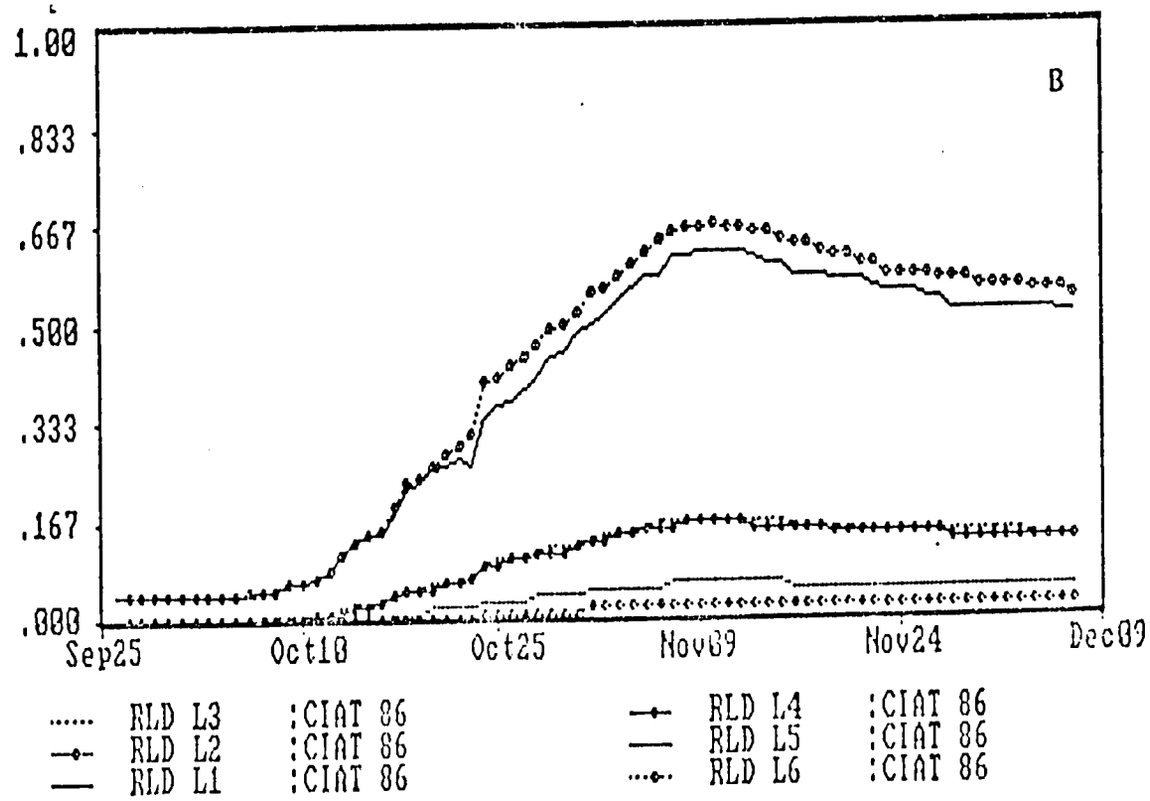


Figure 5. Predicted root length density for each soil layer (L1, L2, L3, L4, L5, L6) at Gainesville (A) and CIAT (B).

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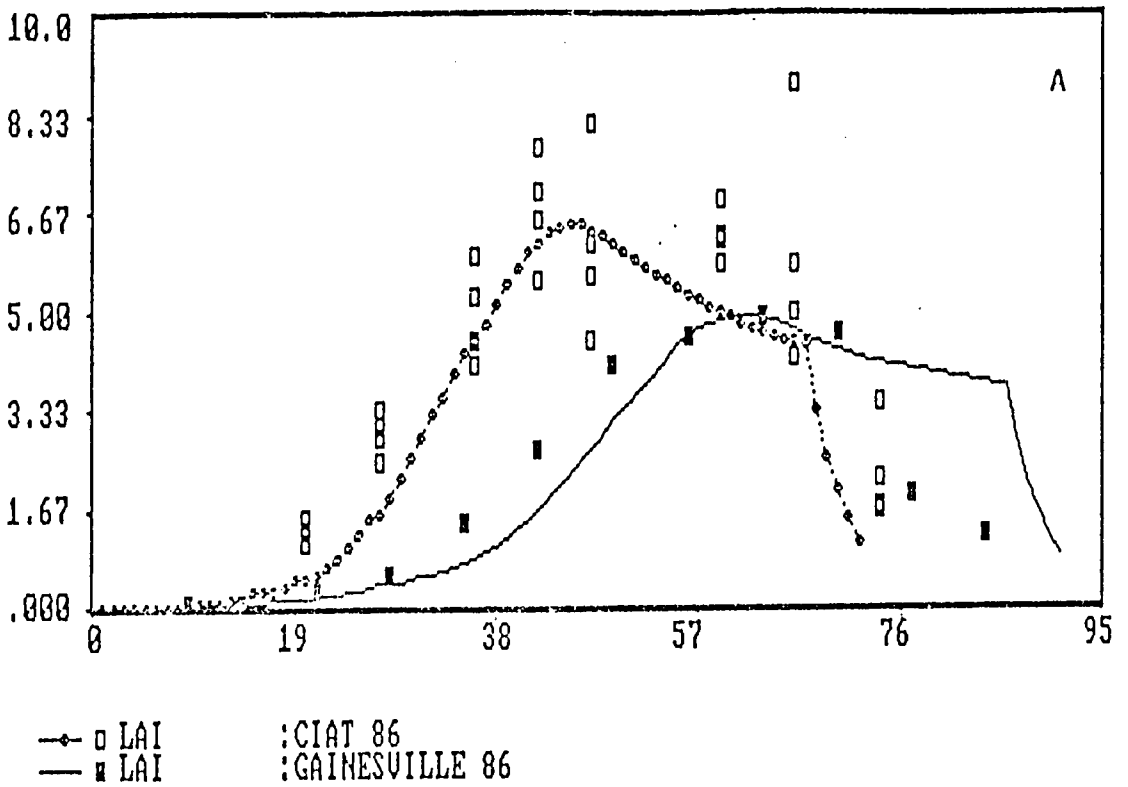

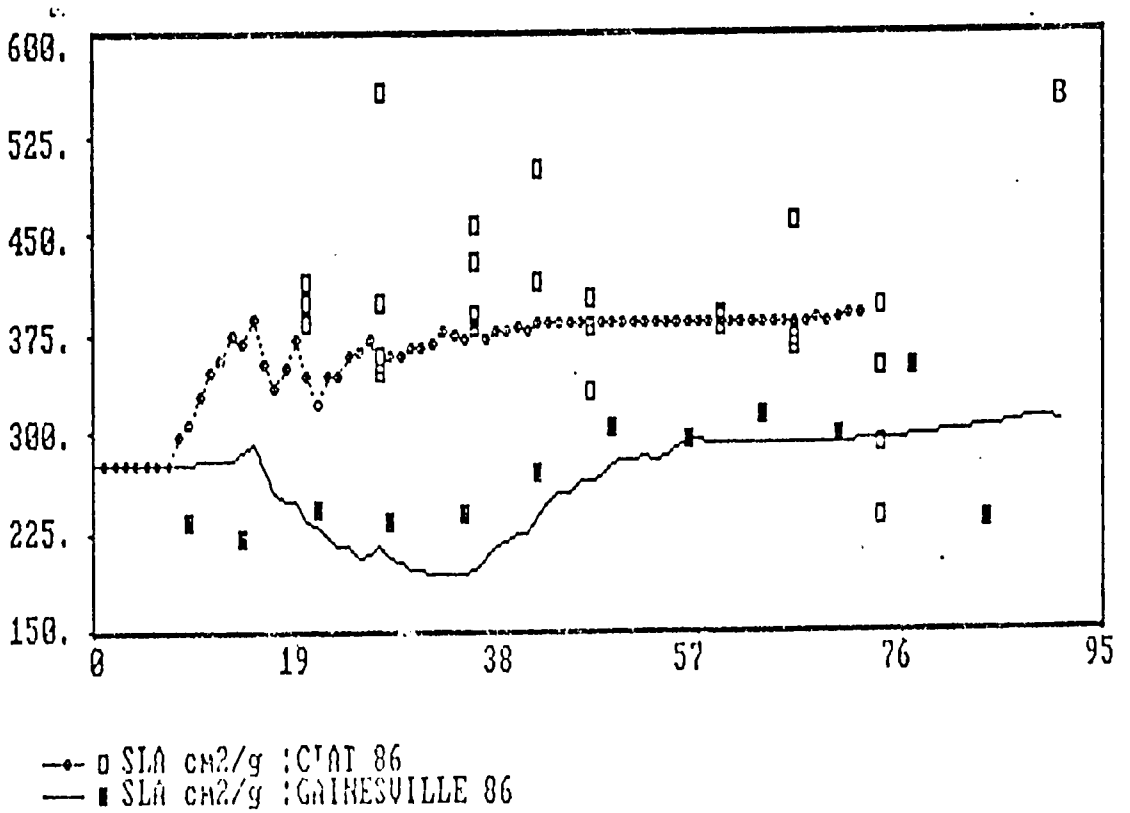

Figure 6. Predicted (*lines*) and measured (*symbols*) leaf area index (LAI) (A) and specific leaf area (SLA) (B) for "Porrillo Sintetico" at Gainesville (A) and CIAT (B).

USE OF MODELS IN STUDIES OF DROUGHT TOLERANCE [1,2]

Gerrit Hoogenboom, J. W. Jones, and J. W. White [3]

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[1] Paper presented at the Bean Drought Workshop. Centro Internacional de Agricultura Tropical, Cali, Colombia. October 20, 1987.

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INTRODUCTION

Traditionally most of the research in agriculture has been conducted under either field or controlled environmental conditions in greenhouses. The data collected during the experiment were analyzed by hand or with hand calculators. After computers were introduced some of the analysis procedures were replaced with computer programs. Currently statistical analysis techniques are widely used by most agricultural researchers to calculate the significance of their experimental results and to proof the validity of their original hypotheses. Only a few researchers, however, have actually gone further and tried to apply their models, developed on computers, under practical agricultural conditions or in farmer's fields. Unfortunately many agronomists trained in the traditional schools are still apathetic against the use of computers in agriculture, mainly because they are unfamiliar with the computer's capabilities and the potential of computer applications. This has prevented a mutual cooperation between computer and systems analysts on one had and agronomists on the other hand.

During the last 15 years a new research discipline has slowly emerged in agriculture. Computer simulation or modeling integrates the knowledge of such fields as soil physics, soil chemistry, plant nutrition, crop and plant physiology, biochemistry, agrometeorology, and agronomy with systems analysis, mathematics, and computer science. In computer simulations the functioning of physical and physiological systems is represented through relational (Gold, 1977) and Forrester diagrams (Forrester, 1971). These diagrams are then translated into mathematical models and implemented on computers (France and Thornley, 1984; Jones et al., 1987). If accurate plant models have been developed, the models will be able to predict correctly what is occurring under real field conditions.

Models can be very simple and have only one or two equations, or they can be extremely complex and consist of hundreds of equations. As a result some models can be implemented on simple hand calculators or hand computers, while others need the latest and fastest super-computers. A simple model in agriculture will predict yield as a function of total seasonal radiation, temperature, and rainfall. A complex model will also predict

final yield, but will require hourly inputs of radiation, air and soil temperature, rainfall, relative humidity, and wind run. It will calculate the detailed physiological processes of water uptake, transpiration, photosynthesis, organogenesis, biomass partitioning, and other processes at one minute time intervals. Although both models have been developed to be able to predict final yield, the complex model will be more accurate than the simple model. However, it is fairly easy to develop the simple model, but the complex model requires many resources in the form of time, equipment, and manpower both for development and calibration and validation of the model before it can actually be used by other researchers or extensionists (Dent and Blackie, 1979).

CROP SIMULATION MODELS

Many of the computer models which have been developed in agronomy or soil science are dynamic and mechanistic simulation models. These models are called *dynamic* because for each calculation and update of the internal model variables information is needed from the previous time step. For instance, when we are modeling leaf growth, we need to know yesterday's total leaf area in order to be able to predict photosynthesis correctly for today. After we have calculated today's growth and death rates we can update the leaf area with the net increase in area and predict what the total leaf area will be at the end of today. The same process will be repeated for the following days. These models are *mechanistic* because there main objective for development is to describe the actual processes which occur in the plant and to summarize the internal mechanisms of plant growth. As mentioned earlier, we can find relatively simple and relatively complex dynamic and mechanistic computer models.

We can also make a distinction between the objectives and goals behind the various crop modeling efforts. Some models have been developed to study only certain special aspects of plant growth and development, e.g. reproductive development, seed growth, stomatal resistance, or root water uptake. As result these models contain many details which relate to the processes they simulate, but the rest of processes which occur in the

same or other organs of the plant are completely ignored. The main purpose of these models is to study and test certain hypotheses which relate to the processes they describe and simulate. They are therefore called *research* models because they are mainly used for research purposes. On the other hand there are management models, which in most cases include a more complete, but simplified, description of plant growth and development. The models will respond to differences in irrigation or fertilization regimes, planting dates, cultivar choice, etc., and will predict yield as a function of management inputs and cultural practices. These models are called *management* models because there main purpose is to study the effect of management decisions on final yield and yield components. Of course many models have been developed which contain components of both types of models.

LEGUME MODELS

At the University of Florida a crop modeling effort was initiated to mainly study the effect of irrigation on growth, development and yield of soybeans (*Glycine max* [L.] Merr.). As a result of this research project a simulation model has been developed which contains both management and research components. The computer model, called SOYGRO, simulates the different growth processes in the soybean plant from planting until harvest maturity, and predicts total growth and development at the different vegetative and reproductive growth stages of the soybean plant. Although the main goal of the model SOYGRO is to predict yield, it also simulates other physiological processes as a function of environmental conditions. The design, development, and construction of a simulation model is a continuous process which always needs improvements, and therefore several versions of the model SOYGRO have been published (Wilkerson et al., 1983, 1985; Jones et al., 1988).

Since 1985 a model is being developed which will simulate vegetative growth, reproductive development, and final yield of common bean or dry bean (*Phaseolus vulgaris* L.). Only a few models have been reported in the literature which simulate growth of dry bean (White, 1981). The code of the soybean model SOYGRO was used as a standard

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and modifications were made to the different submodules and input files of the model to describe the specific growth and development characteristics of dry bean (Hoogenboom et al., 1986). A third legume model which has been developed by the cropping systems analysis group at the University of Florida is the peanut (*Arachis hypogaea* L.) model PNUTGRO (Boote et al., 1988). All three models are part of a U.S. Agency of International Development project called IBSNAT, International Benchmark Sites Network for Agrotechnology. The IBSNAT project is designing a new methodology for planning agricultural development and controlling farming outcomes in the developing countries. One of major techniques used to accomplish these objectives are computer models and data bases (Jones, 1986).

MODEL APPLICATIONS

Although computer modeling is a fairly new discipline, potential applications have already been widely published in the literature. Jones et al. (1985), Jones (1986), and Ritchie (1986) showed the use of computer models to improve management decisions. Elwell et al. (1987) determined the potential yield limiting factors of soybean through crop modeling. Programs are also currently being developed to apply models on a farm scale level, integrating both crop models and farming systems research models (Phornton and Dent, 1987; Jagtap and Jones, 1987).

Computer models have also been used to study the specific impact of drought on crop production and yield. Pisani (1987) used the CERES-MAIZE model, a dynamic simulation model which predicts growth and yield of corn (*Zea mays* L.) (Jones and Kiniry, 1986) to assess drought impacts on maize during early stages of the growing season. Boote and Jones (1986) presented the potential and limitations of crop growth simulation models for the evaluation of crop varieties and cropping systems in arid and semi-arid regions. They used the peanut model PNUTGRO (Boote et al., 1988) to create potential cultivar characteristics and crop management conditions and predicted growth, development, and yield of these new cultivars for environmental conditions in Gainesville, Florida, and

Niamey, Niger.

In this paper we will demonstrate the use of the dry bean model BEANGRO as an example of the application of a crop simulation model in studies of drought tolerance. We will especially concentrate on bean plant characteristics which have the potential for drought resistance and avoidance (White and Castillo, 1988) and will predict the yield of these new dry bean cultivars under drought conditions at CIAT, Colombia. The advantage of using simulation models for these types of applications is that many theoretical experiments can be conducted with the aid of crop models and computers without actually investing in any resources for field experiments. The results of these simulations will show if modifications to the plant have a potential for an economical increase in yield (Wallace, 1985). A breeder can then pursue these characteristics and try to concentrate his breeding program around these drought resistant traits (White and Singh, 1988).

DRY BEAN MODEL DESCRIPTION

The first version of the dry bean model BEANGRO during the conversion process from the soybean model SOYGRO was described by Hoogenboom et al. (1986A, B). A more detailed description of the model was presented during the Bean International Trials Workshop (Hoogenboom et al., 1988A). Currently a first version of the bean model is being finalized and prepared for public release. Also a user's guide, which explains the procedure of running the model on a micro-computer (Hoogenboom et al., 1988B), and technical documentation will be published.

The dry bean model predicts vegetative growth and reproductive development. A description and explanation of the module which simulates reproductive development for all three legume models was given by Jones et al. (1988). The model has separate routines which calculate photosynthesis, respiration, biomass partitioning, growth of leaves, stems, roots, and, after flowers have been initiated and pods are set, pod and seed growth. The model also accounts for infiltration of rainfall and irrigation into the soil profile, saturated

and unsaturated flow for the different soil layers, water uptake, soil evaporation, and transpiration. The soil water balance section is based on generic soil water and root growth modules, developed by Ritchie (1985) and used in the CERES and SOYGRO models. The potential daily evapotranspiration rate is calculated from temperature and radiation based on the equilibrium evapotranspiration defined by Priestly and Taylor (1972).

The vegetative and reproductive development sections use predicted hourly temperatures and night length to calculate several thermal and photothermal accumulators and are updated at hourly intervals. All other plant processes defined in the model are calculated and updated after each 24 hour time step. BEANGRO requires daily weather data in the form of total radiation, minimum and maximum temperature, and total rainfall as inputs. Also needed are crop management practices as row and plant spacing, planting date, cultivar, and irrigation and fertilization regimes (IBSNAT, 1988). Finally information about the soil profile and its soil water conditions is required. This is especially important when the model is used to study the effect of drought on crop production and yield. For each soil layer, a saturated soil water content, a drained upper limit, which is similar to field capacity, and a lower limit, or permanent wilting point, are defined. Other parameters which define soil albedo, saturated conductivity, and root distribution can be estimated based upon the soil texture of each layer. More information about the input requirements of the simulation models is given in IBSNAT Technical Report 5 (IBSNAT, 1986).

For initial development of the model experiments were conducted at the Irrigation Research and Education Park of the University of Florida during the 1985 Fall season (Hoogenboom et al., 1986), and during the 1986 Spring season (Mahamadou et al., 1987). Although several different irrigation regimes were applied during the growing season, only data from the non-stressed and fully irrigated plots were used to calibrate the model. At the same time the model was also tested with data sets collected at CIAT, Colombia, during the 1985 and 1986 growing season (White, personal communication). The model predicted growth of the different plant components accurately for both locations (Hoogenboom et al., 1988), although still modifications in the model are needed to be able to predict yield correctly under a wide range of environmental conditions.

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SIMULATION CONDITIONS

For special applications under different drought and irrigation conditions, the dry bean model was validated with experimental data collected during the 1986 growing season (Mahamadou et al., 1987). Beans in this experiment were grown under five different irrigation levels, from daily irrigated to rainfed only. All the legume models show a very strong response as a function of the total amount of accumulated water received during the season, either from rainfall and/or irrigation, mainly because the initial version of SOYGRO was developed to study irrigation management strategies. The dry bean model predicted growth and yield of the rainfed and daily irrigated treatments accurately, while some of predictions for the other irrigation treatments still can be improved. Overall the predictions of the model were within the error range of the field observations. Therefore the model could be used to demonstrate the potential of crop models for drought studies in dry beans. The main objective of this study was to look at the qualitative responses of the model and not at the quantitative. Thus, the actual precision of the simulated results is not very important.

CIAT is geographically closer located to bean growing areas than the University of Florida. Thus, experimental conditions at CIAT were used to define the parameters which describe the soil profile characteristics and crop management data files of the model. Although conditions for extreme drought are not very common at CIAT, the institute is located in an area which has relative wet and dry seasons and therefore the model has a potential to show differences in response to CIAT's weather conditions. CIAT was also the only tropical location which had enough information available with respect to the weather and soils data to be able to initiate and run the model. Possible future applications will be in the Jutiapa region, Guatemala, and in Durango, Mexico.

CIAT is located close to the equator (latitude 3.3 ^{o}) and therefore the effect of varying daylength on development is not very important because of the fairly stable

daylength during the entire year. Also daily total radiation and temperature only show minor variations over the entire growing season. Overall, most of responses to the environmental conditions will therefore be a function of seasonal rainfall. The soil at CIAT is a silty clay (loamy clayey, typic Pellustert) with a rather large water holding capacity. Soil data collected at CIAT (White, personal communication) were used to define the soil water characteristics of each layer of the profile. For these studies the genetic characteristics of the cultivar "BAT-477" were selected to define the cultivar characteristics. "BAT-477", a new line developed at CIAT, has shown a potential for higher yields under relatively dry conditions. The cultivar "BAT-477" was also studied in the experiments both in Gainesville and at CIAT and was used for initial development of the model. Unfortunately only 8 complete years of historical weather data were available from CIAT, e.g. 1979 through 1986. In the new Decision Support System for Agrotechnology Transfer (DSSAT), options are available to analyze long term effects through weather generators and strategy assessment techniques (Jagtap and Jones, 1987). However, in the study presented in this paper "real" weather data were used. Actually measured daily minimum and maximum air temperature, rainfall, and radiation were stored in data files, read at daily time intervals by the computer model and used to calculate all the processes simulated by the model.

PLANTING DATE

To study the effect of planting date as a function of seasonal and yearly weather variation, the first simulation was started on January 1. This actually means that the model assumed that the planting date of the crop was January 1, and planting was initiated at intervals of 15 days until October 15, for a total of 20 planting dates. The simulations were then repeated for each year, which resulted in a total of 160 simulations. In Fig. 1 total accumulated rainfall received by the bean crop during the growing season is shown as a function of planting date. For each planting date a total of 8 points is shown, representing the 8 years for which the simulation was run. There was a strong variation in total rainfall, with planting dates around the end of June and the beginning of July (calendar day 150 to 170) which showed less than 150 mm, while early plantings in March (calendar day 60 to

90) or late plantings in September (calendar day 245 to 275) showed rainfall as high as 350 to 400 mm. The rainfall pattern was clearly bi-modal, with the highest amounts corresponding to the rainy season and the lowest amounts to the dry season. Especially during the wet seasons a very strong year to year variation was predicted. The March 1 (calendar day 60) planting date showed a minimum of 150 mm and a maximum of 450 mm during the 8 years simulated.

A similar bi-modal distribution was found when simulated total biomass at the end of the season was plotted as a function of planting date (Fig. 2). The maximum biomass predicted by the model varied between 6000 and 7000 kg/ha for all planting dates except during May, June, and July, which were the dry months. The lowest biomass varied between 0 and 1000 kg/ha, which was mainly predicted during the dry months, but was also found for some of the January and March planting dates. From Fig. 1 and 2 it can be concluded that there was a linear relationship (R^2 = 0.63) between total rainfall during the season and biomass harvested at the end of the season (Fig. 3). For total amounts of rainfall larger than 300 mm, total biomass reached a maximum around 6000 kg/ha and did not increase as a function of rainfall at higher amounts.

Yield followed a very similar pattern as a function of planting date, as was found for observation for rainfall and biomass (Fig. 4). The highest predicted yields varied between 3500 and 4000 kg/ha, while the lowest yields were no yield predictions (0 kg/ha). Although most of the zero-yield planting dates were simulated for the May and June planting dates, they were sometimes also predicted for other planting dates where more total rainfall had been received during the season. Apparently the rainfall during some of those years was not evenly distributed over the entire growing season and therefore not enough soil moisture was present during seed filling to establish a high yield. For the conditions of these simulations only the planting dates from August 15 through October 1 predicted a minimum expected yield of 1000 kg/ha, with no yield lower than this amount. Although yield was strongly dependent on rainfall , this relationship only held for medium amounts of rainfall received during the season and not for either extreme wet or dry conditions (Fig. 5). For rainfall between 150 and 200 mm there was a linear relationship (R^2 = 0.59) with yield,

which increased from 0 to 3000 kg/ha. For total rainfall below 100 mm a zero yield was predicted.

These results show that computer simulations of plant growth can be used to determine the possibilities of sustainable agriculture in certain regions. When several years of historical weather data are available, similar computer simulations can be made to determine yield as a function of planting date. When all results show a low yield, independent of the year or the planting date, there is a high chance that the region will be unable to produce enough agricultural products to either satisfy their own need for food or to trade or sell beans in exchange for other products. The risks involved are then too high for the farmers to invest in seed and fertilizer and no net positive return can be expected. On the other hand, if the model shows that certain planting dates have a higher potential yield than others, it might be worthwhile for breeders to select for drought resistant traits which will increase the productivity of beans under those conditions.

YIELD AND PROBABILITY

In the previous section we demonstrated the response of the dry bean model BEANGRO to periods of drought. During dry periods a yield decrease, with a minimum of zero yield, was predicted when compared with periods which receive higher amounts of rainfall. Rainfall at CIAT varies strongly as a function of time (Fig. 1), and therefore planting dates need to be selected for further simulations. In these simulation run one or more typical plant traits characteristic for drought stress will be modified and predicted yield and yield components will be analyzed under both dry and wet conditions. Cumulative probability functions (Fig. 6) were used to select the months which had both low and high yields. Although these probability functions are normally used to determine dominant or efficient crop management strategies (Thornton and Dent, 1987), we used these functions to find an equal distribution of yield over the entire potential yield range (Fig. 4).

The probability function shown in Fig. 6 is the accumulated yield for all combinations

of 8 years and 20 planting dates. The function indicated that there is a 10 % probability under these environmental conditions that there is no yield (0 kg/ha). There was a 50 % probability that yield was less than 2000 kg/ha (shown by the large arrows). You can also look at the inverse of the cumulative density function : there was a 65 % (100 % - 35 %) probability (small arrows) that yield was higher than 1000 kg/ha. In general these yields predicted for CIAT's environmental conditions were high compared with most drought areas like the highlands of Mexico, where yield many times is never higher than 1000 kg/ha. However, these predictions presented show the possibilities of applications of the model for drought conditions.

Separate cumulative probability curves were calculated for all planting dates in each month. During the month of June there was a 50 % probability of 0 kg/ha yield and the maximum yield predicted was 1000 kg/ha. During the month of March the probability was 80 % that yield was higher than 2000 kg/ha. The results of June and March were extremes for respectively severe dry and severe wet conditions for the 8 years of weather data used in this study. February and August planting dates showed a diagonal cumulative probability distribution with an equal probability for all yield levels within the predicted range. Therefore these two months were used for further simulations in which parameters representing certain traits related to drought avoidance were modified.

CULTIVAR CHARACTERISTICS

Until now we only demonstrated the use of the model for analysis of the variability of yield as a function of the uncertainty of weather conditions, especially rainfall. The model, however, can also be used to modify specific cultivar traits and characteristics and study the effect of these modifications on yield and yield components. Boote and Jones (1986) demonstrated this application with the peanut simulation model. In this paper we have taken a slightly different approach. Certain parameters which are characteristic for a certain trait related to drought and drought resistance, were selected and modified at + 10 % or - 10 % intervals. The model was then run for both the February and August

planting dates and the 8 years of weather data from CIAT, and finally yield and other model predictions were plotted as a function of this specific cultivar trait.

Specific Leaf Area

The assumption was made that thick leaves and a smaller total leaf area per plant will reduce the total amount of water lost through transpiration and consequently the crop will be more efficient with available soil water. On the other hand a bigger canopy, consisting of relative thin leaves, has a potential for higher total canopy photosynthetic rates and consequently biomass production and final yield. The standard value in the model for Specific Leaf Area (SLA) is 300 cm^2/g and SLA was varied at ± 15 cm^2/g intervals between a minimum SLA of 195 cm^2/g and a maximum SLA of 405 cm^2/g. Total mean, maximum, and minimum predicted biomass at the end of the season are shown in Fig. 7. The minimum biomass was independent of SLA, but maximum biomass increased as a function of SLA from 4000 kg/ha to 7000 kg/ha. The mean predicted value for all planting dates and simulation years increased from 2000 kg/ha to 4000 kg/ha when SLA increased from 195 cm^2/g to 405 cm^2/g.

Yield showed no response to SLA for values higher than 300 cm^2/g, the value used in the standard version of the model (Fig. 8). However, when SLA decreased from 300 cm^2/g to 195 cm^2/g and leaves became thicker, yield dropped from 1750 kg/ha to 1000 kg/ha. Thus, for these simulations the model predicted the lowest yield for canopies with low SLA's, thick leaves, and small amounts of total leaf area, while the highest yields were predicted for canopies with the highest SLA's and the thinnest leaves.

Water use efficiency (WUE), calculated as yield per unit of transpiration (yield efficiency, Tanner and Sinclair, 1983), showed a maximum at a SLA of 265 cm^2/g, close to the SLA of 300 cm^2/g used in the model (Fig. 9). For both lower and higher values of SLA the WUE decreased. This was caused by a slowly increasing total accumulated transpiration rate as a function of SLA, while yield reached a maximum at a SLA of 300

cm^2/g. Thus the hypothesis that the water use efficiency is highest for plants with the smallest SLA and the thickest leaves is rejected based on these simulation results. However, the model predicted that decreasing the SLA slightly from the current value of 300 cm^2/g (Fig. 9, broken line) to 265 cm^2/g will increase the overall yield or water use efficiency.

Biomass Partitioning to Roots

The second hypothesis made is that if a larger fraction of total carbohydrates is distributed into the root system, the plant will have more soil volume to explore and extract soil water and therefore will be able to resist drought stress for a longer period. The current parameter defined in the model was used as a check value, and this parameter was increased or decreased at steps of ± 2 %. This resulted in a minimum of 88 % and a maximum of 116 % of the original biomass fraction distributed to the root system. The model predicted that the highest yield will be occur when the largest fraction of carbohydrates will be partitioned into the roots, while the lowest yield will be found when the smallest fraction of carbohydrates is distributed to the roots (Fig. 10). There was no significant effect of root partitioning factor on total above ground biomass production. Biomass was fairly constant over the entire range of partitioning and varied around 4000 kg/ha (Fig. 11).

The model illustrates that modifying plant characteristics which affect or relate to biomass partitioning into the root system has a potential to improve yield. As part of the experimental study used to calibrate the model, it was found that the root density of all five irrigation treatments was very similar for all depths, while there was a significant difference in total above ground biomass (Hoogenboom et al., 1988C). Unfortunately, roots are the most difficult components of the plant to study and many aspects of the rhizosphere have often been ignored in previous investigations because of labor intensive measurements. The model, therefore, can be used in preliminary studies to investigate the many trait combinations which have a potential for drought tolerance or resistance to select the most effective traits which can be further pursued under field or greenhouse conditions.

Maximum Rooting Depth

In the third hypothesis it was assumed that a deeper penetrating root system has the potential to increase the plant's resources to extract water from deeper soil layers, which previously have been unexplored by the root system. Because the plants will still have the same total root biomass and root length, actual root length density will decrease with a lower maximum rooting depth and will increase with a shallower maximum rooting depth. It is assumed in the model that roots will not grow deeper than the maximum rooting depth. This can either be caused by genetic constraints of the cultivar or physical factors in the soil profile. For this study the rooting characteristics of the cultivar determine the maximum rooting depth and no other physical soil conditions, except soil water, limit root growth.

Under standard conditions the maximum rooting depth of the model for the soil conditions at CIAT is 1.25 m. The maximum rooting depth was varied at increments of ± 0.05 m. A very shallow soil of 0.6 m was selected for the minimum depth, while the maximum depth was 1.5 m (Fig. 12). The average biomass gradually increased from 3000 kg/ha to 4000 kg/ha when maximum rooting depth increased from 0.6 m to 1.2 m. For maximum rooting depths below 1.25 m there was no significant difference in the mean total biomass predicted at the end of the season. Yield increased from 1300 kg/ha to 2100 kg/ha, with most of the increase occurring when rooting depth was lowered from 0.6 m to 1.25 m (Fig. 13). Except for the shallow rooting depth, WUE increased significantly when maximum rooting depth increased and roots were allowed to penetrate deeper into the soil profile (Fig. 14). These model predictions show that yield, biomass, and WUE will be higher for plants with deeper roots, than for plants with shallower roots. Therefore opportunities exist for plant breeders to select for plants which show root systems with deep penetrating roots early during the growing season.

Root Length Weight Ratio

The last rooting characteristic to be studied with the simulation model is the root length weight ratio. This factor is an indication of the thickness of the root system, similar to the specific leaf area of the canopy. Thin roots have a rather high root length weight ratio, while thick roots have a low root length weight ratio. In the model it is assumed that all roots have the same thickness and that there is no difference between tap roots, primary roots, and secondary roots. Growth in the model is based on a carbohydrate balance, and therefore a certain amount of carbohydrate is allocated to the root system. Given a certain amount of root biomass, the root length weight ratio will determine the total length of new root growth. This in turn determines the total root length which is potentially available for water uptake. In general the longer the total root lenght of a plant, the larger the amount of water which can be extracted by the entire root system. In the current version of the model it is assumed that the root length weight ratio is 5000 cm/g, which is a rather low value compared with field observations. For this study we are mainly interested in the relative effects of the parameter modifications, and therefore the actual value is not very important.

The root length weight ratio was changed with increments of ± 10 %, with a minimum value of 3000 cm/g and a maximum value of 10000 cm/g. The root system with a ratio of 10000 cm/g is three times as long as the root system with a ratio of 3000 cm/g. Yield increased from 1350 kg/ha to 2300 kg/ha, with most of the increase occurring when the root length weight ratio changed from 3000 to 6000 cm/g (Fig. 15). Total predicted biomass showed a similar response to the increase in root length weight ratio. It is interesting to note that, while the total root system was confined to the same total soil volume, accumulated transpiration and therefore total water uptake by the root system at the end of the growing season increased significantly when the root length weight ratio increased. A total accumulated transpiration of 135 mm was predicted for plants with a root length weight ratio of 3000 cm/g and a total of 185 mm was predicted for plants with a root length weight ratio of 10000 cm/g (Fig. 16). In all cases the standard deviation was very small, independent of either planting date or weather year.

CONCLUSIONS

In this paper we have shown the potential application of a computer simulation model in studies of resistance or tolerance to drought. Depending on the type and amount of data available, the model can be used to study the potential yield under drought conditions and determine if breeding for higher yield is feasable, or if, due to environmental conditions, yield will never be higher than a certain amount. The model can also be used to concentrate on specific characteristics of plants which will make them more susceptable or resistant to drought stress. Breeders can then use the results of these theoretical studies to concentrate their breeding program. However, one needs to keep in mind that a model is never "perfect", and will never be able to simulate a system completely, like in this example a bean crop. To be able to develop a model, a modeler has to make assumptions, and the results of the model are therefore only valid within the realm of these assumptions. The results shown in this paper, however, clearly show a potential use of models in the field of drought stress studies.

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FIGURE LEGENDS

Figure 1. Total accumulated rainfall for the entire growing season as a function of planting date. There are eight (1979-1986) simulations for each planting date.

Figure 2. Biomass predicted at the end of the growing season as a function of planting date.

Figure 3. Biomass predicted at the end of the growing season as a function of total seasonal rainfall.

Figure 4. Final seed yield as a function of planting date.

Figure 5. Final seed yield as a function of total seasonal rainfall.

Figure 6. Cumulative probability as a function of final yield.

Figure 7. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

Figure 8. Mean, maximum, and minimum predicted seed yield (Δ, X, ± 1 sd.) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

Figure 9. Water use efficiency (yield efficiency) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

Figure 10. Predicted seed yield (Δ, X, ± 1 sd.) as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).

Figure 11. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).

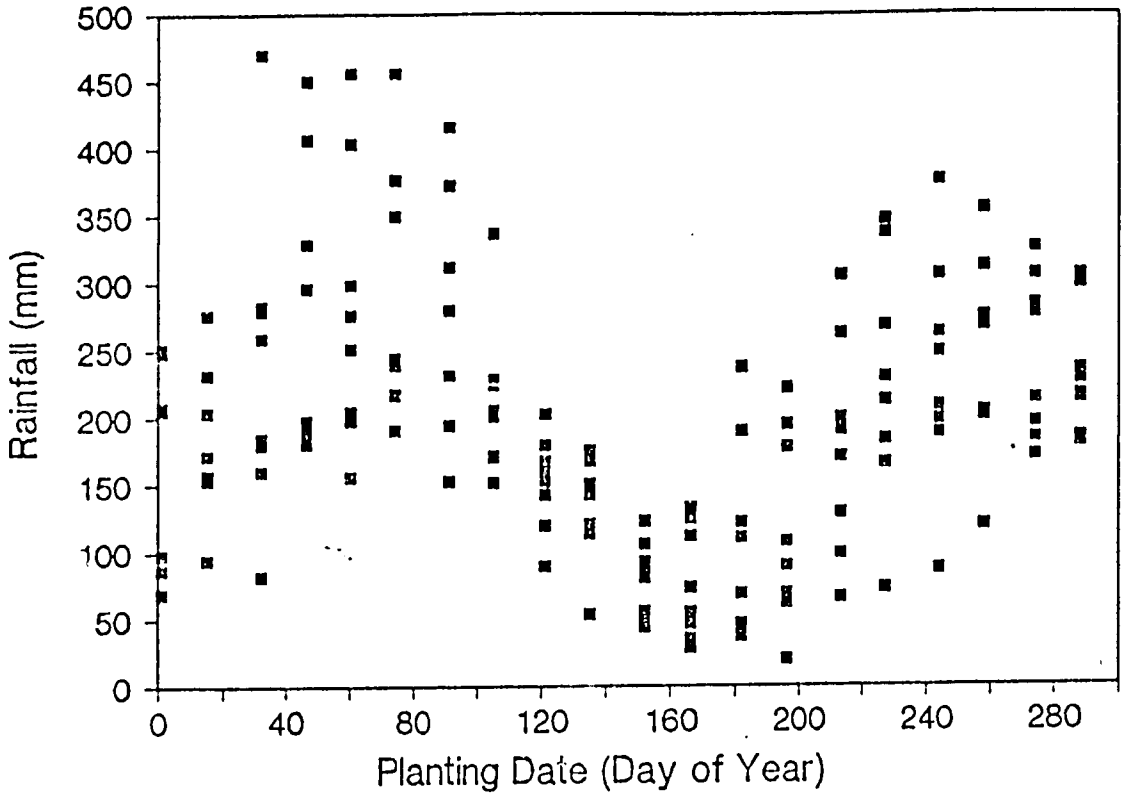
Figure 12. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 13. Predicted seed yield (Δ, X, ± 1 sd.) as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 14. Water use efficiency (yield efficiency) as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 15. Predicted seed yield (Δ, X, ± 1 sd.) as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 16. Total accumulated transpiration (Δ, X, ± 1 sd.) for the entire growing season as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).



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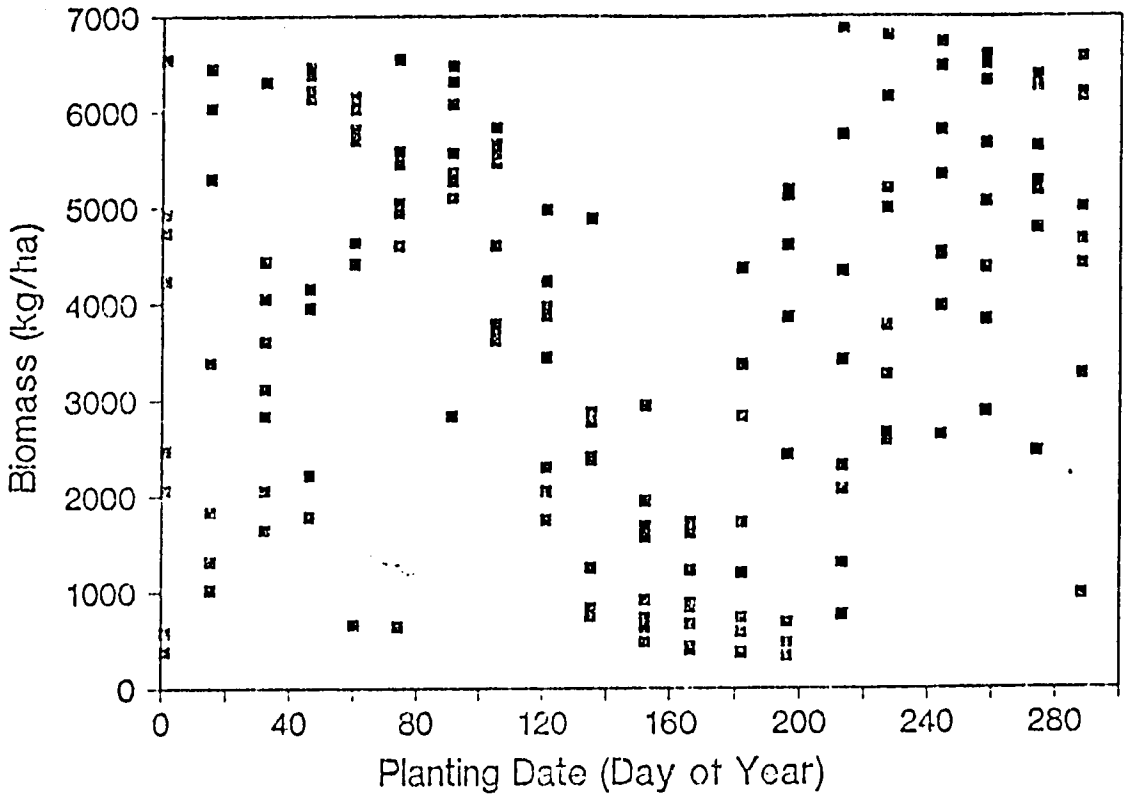


Figure 2. Biomass predicted at the end of the growing season as a function of planting date.

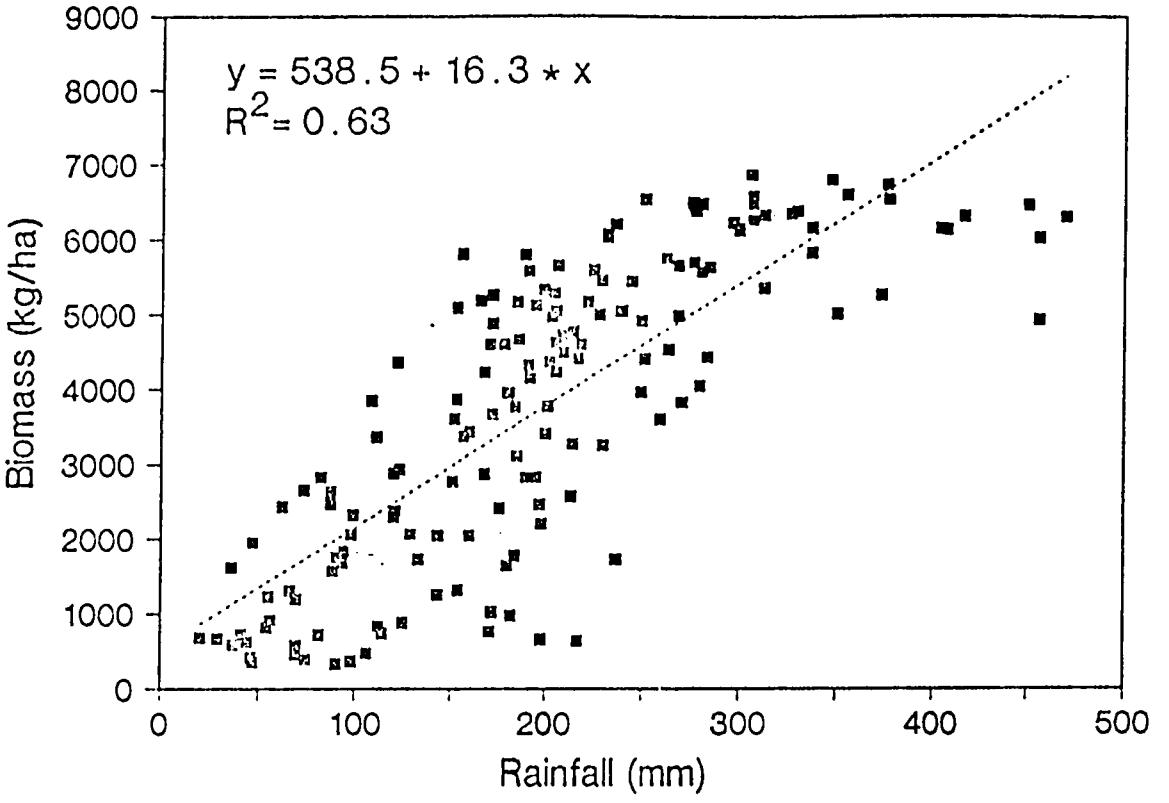


Figure 3. Biomass predicted at the end of the growing season as a function of total seasonal rainfall.

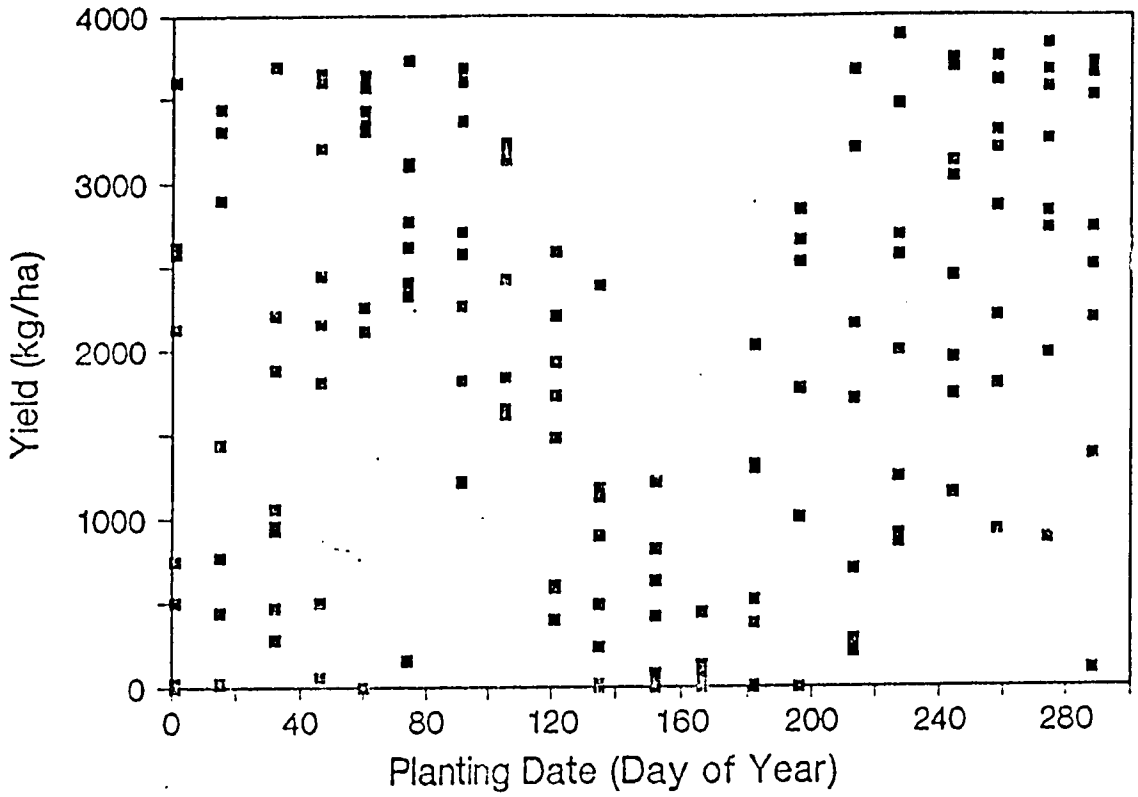


Figure 4. Final seed yield as a function of planting date.

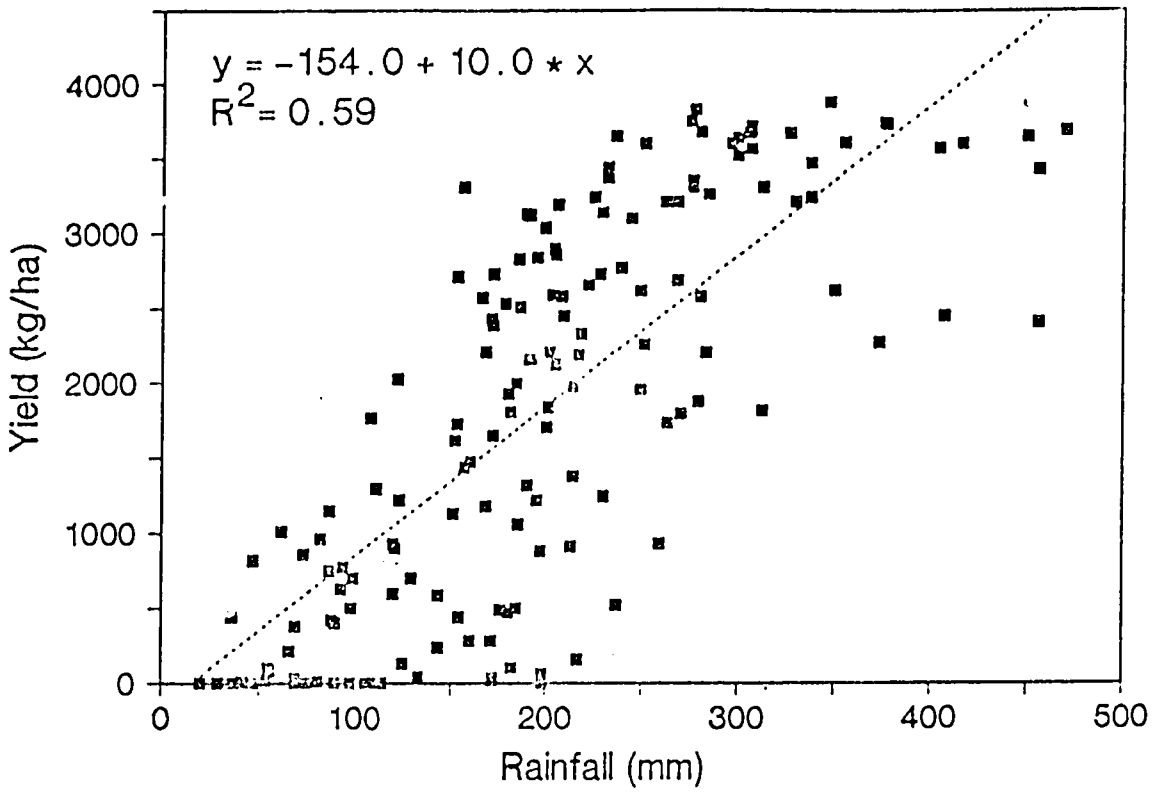


Figure 5. Final seed yield as a function of total seasonal rainfall.

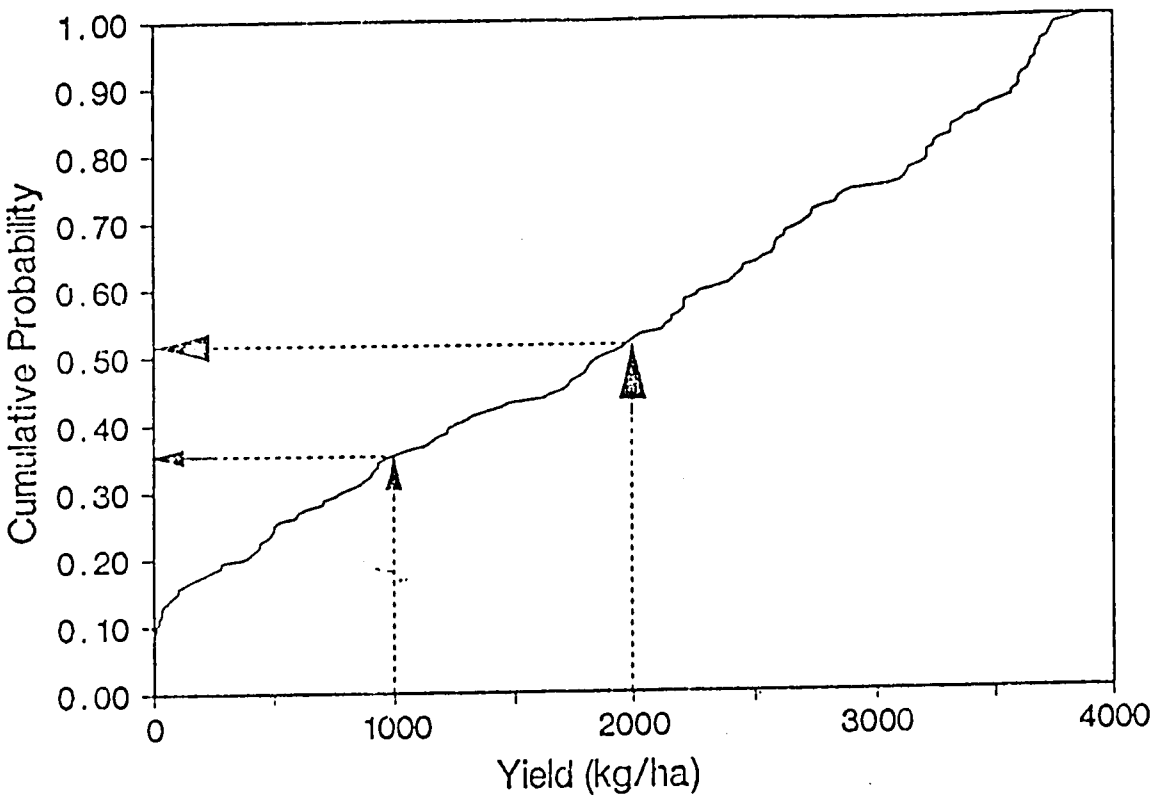


Figure 6. Cumulative probability as a function of final yield.

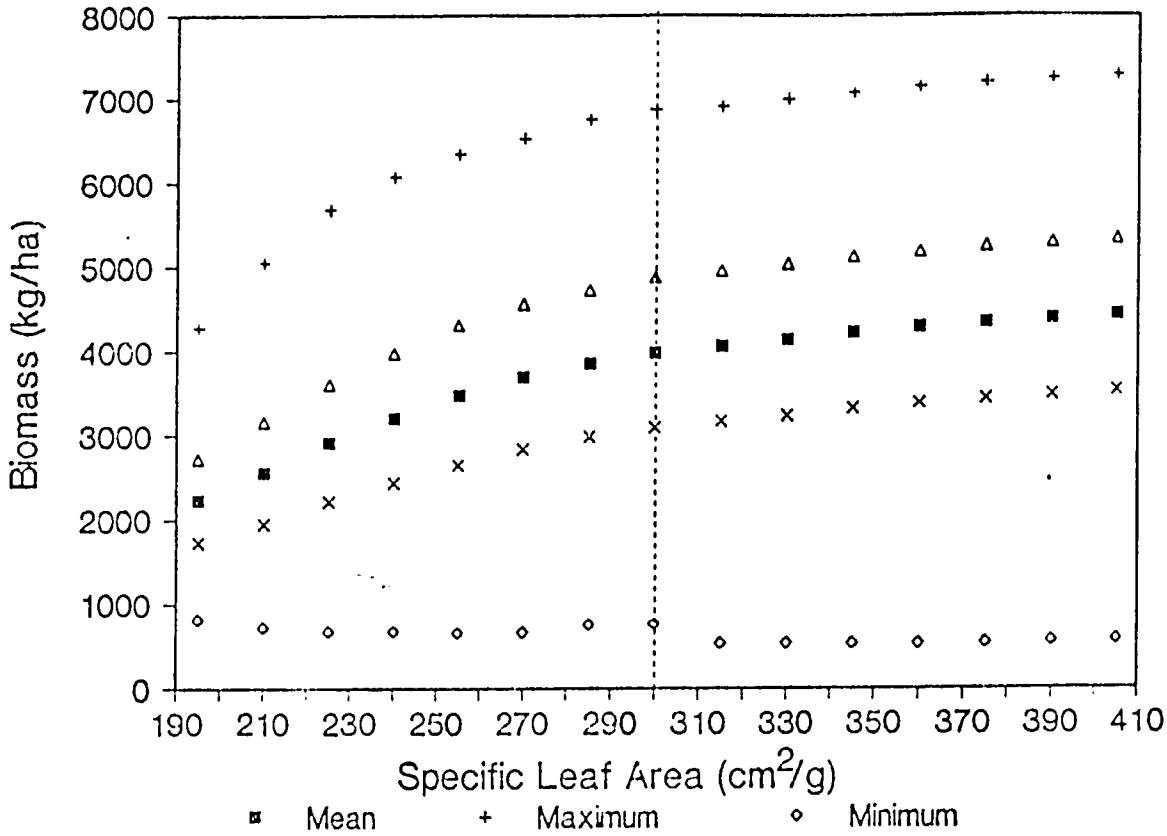
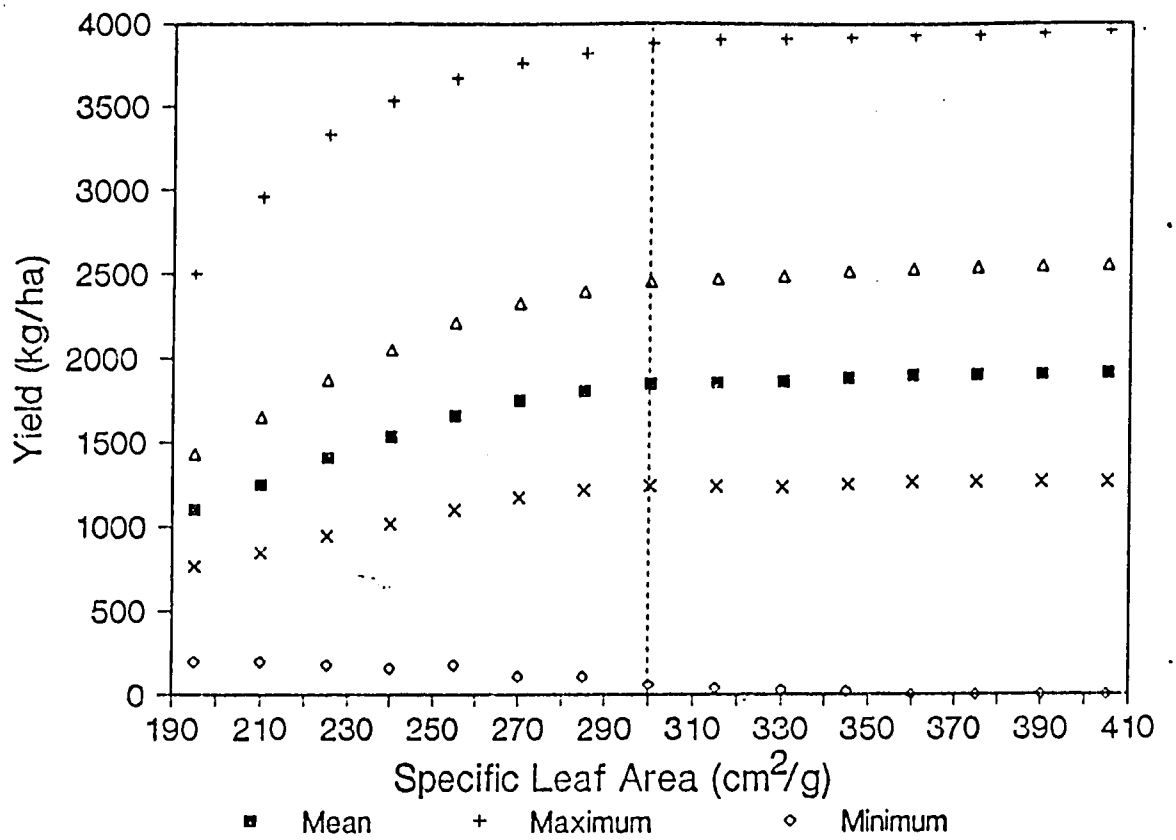


Figure 7. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).



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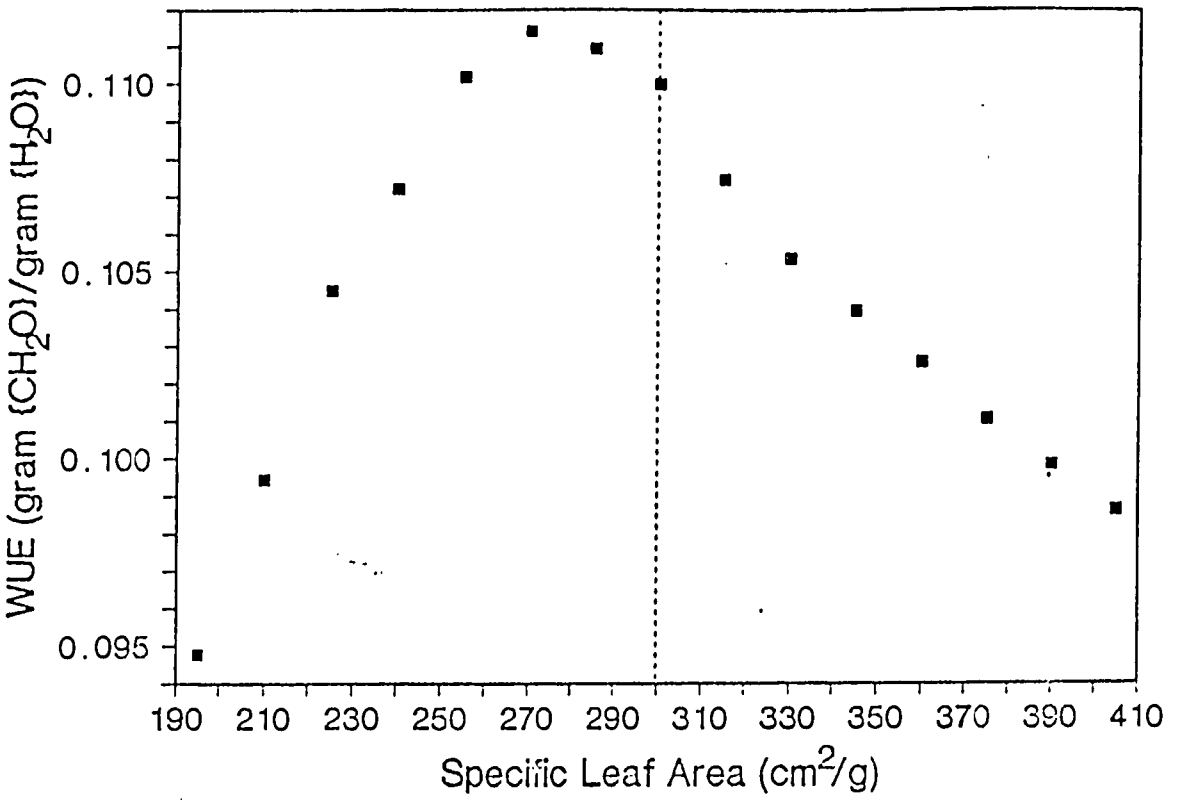


Figure 9. Water use efficiency (yield efficiency) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

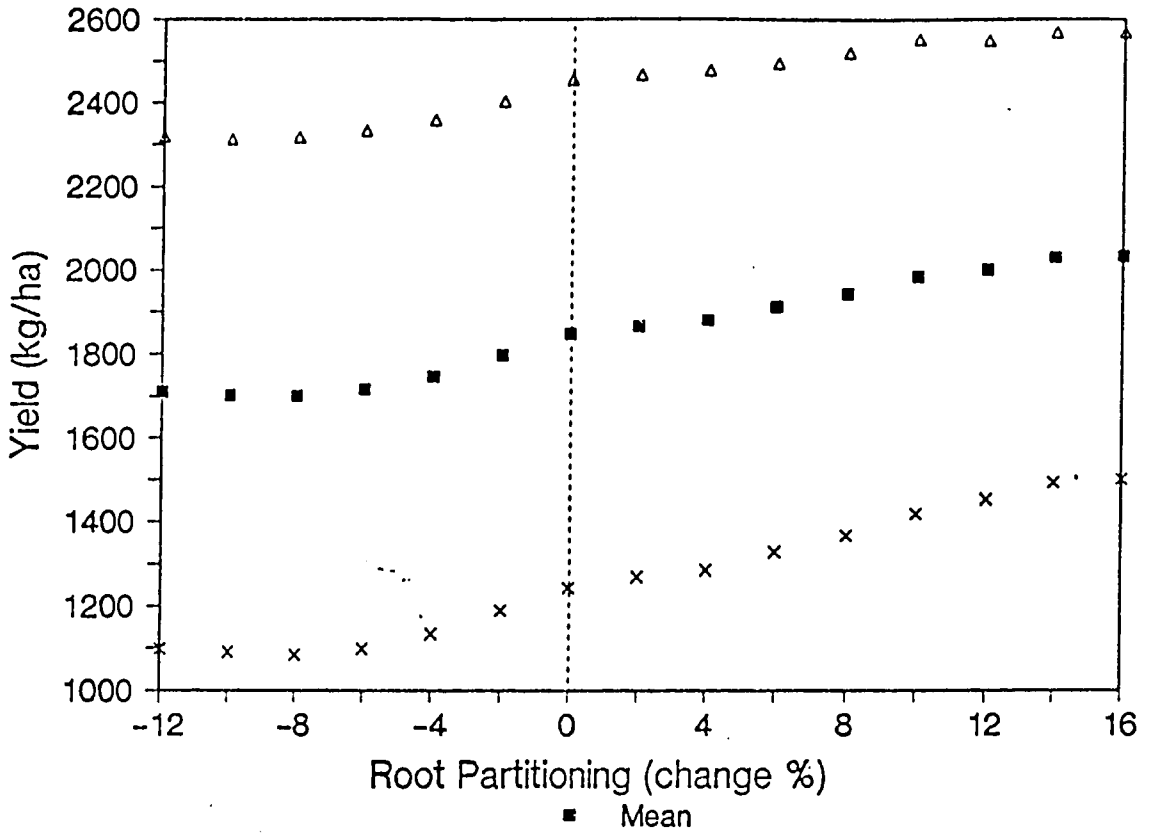
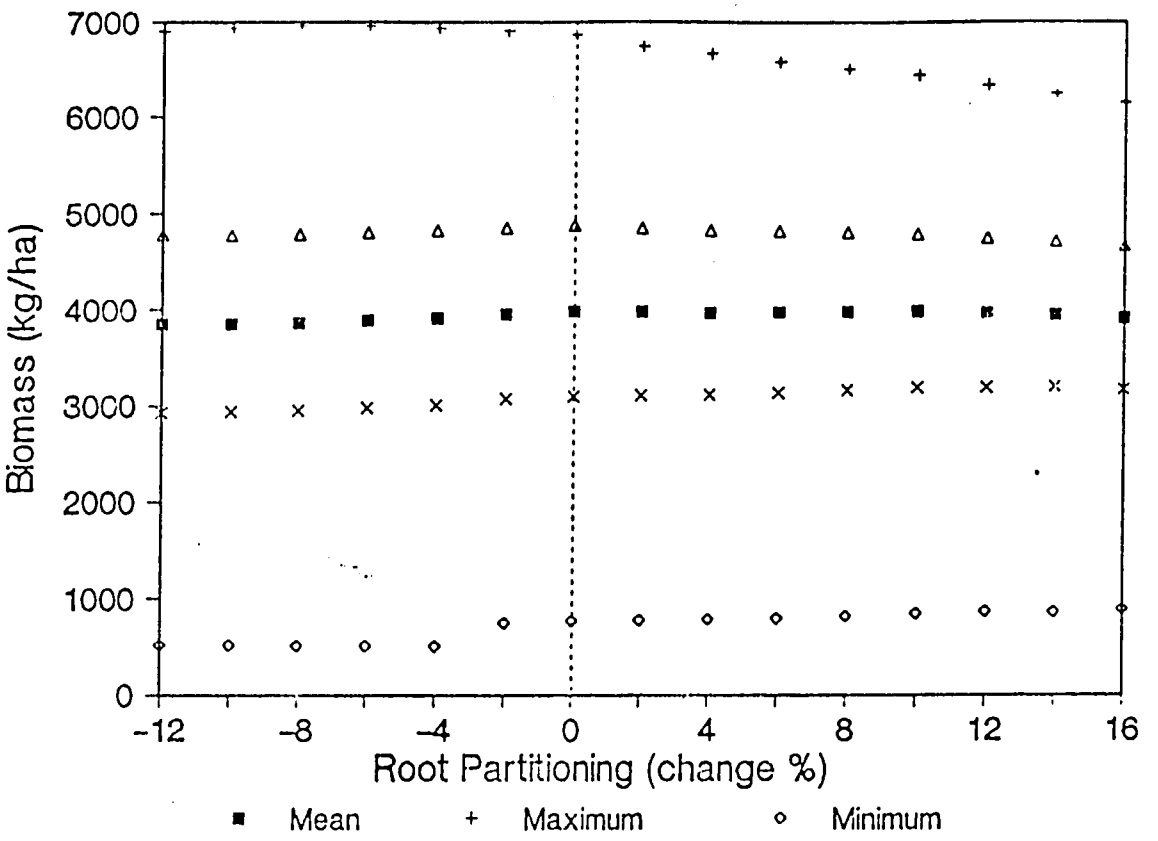


Figure 10. Predicted seed yield (Δ, X, ± 1 sd.) as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).



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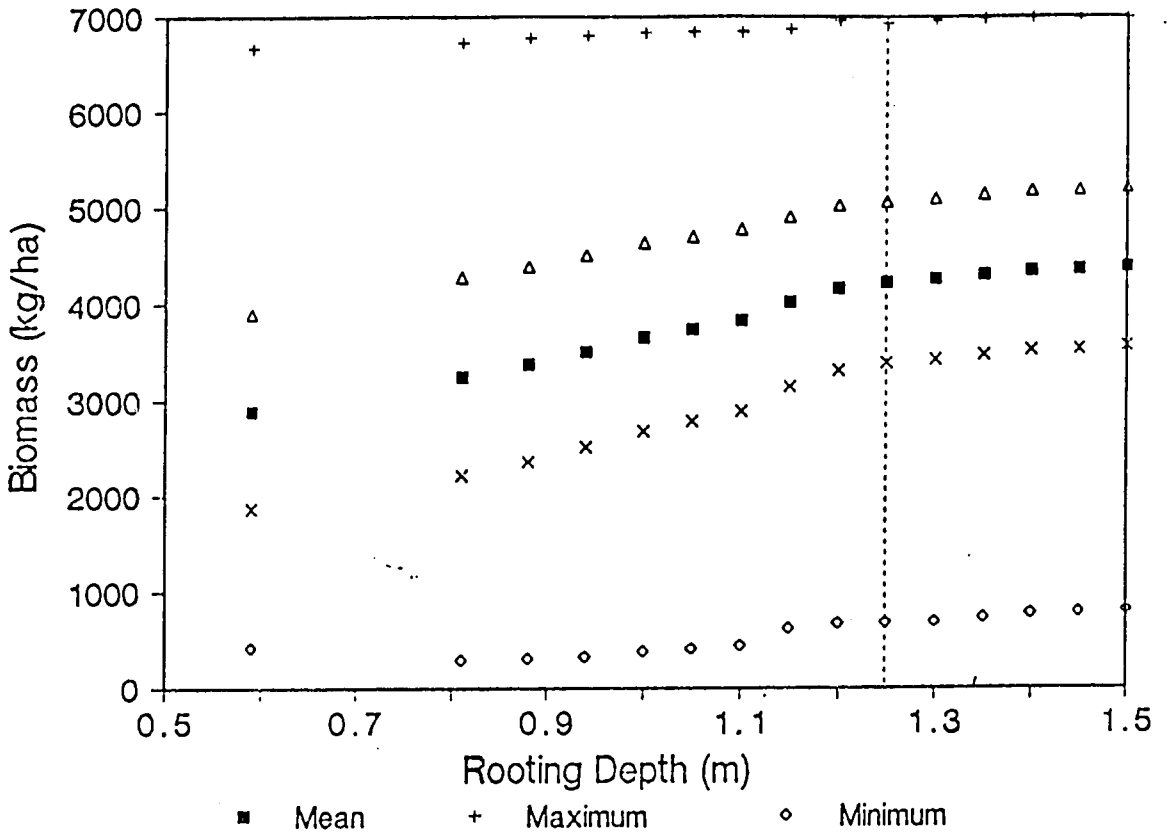
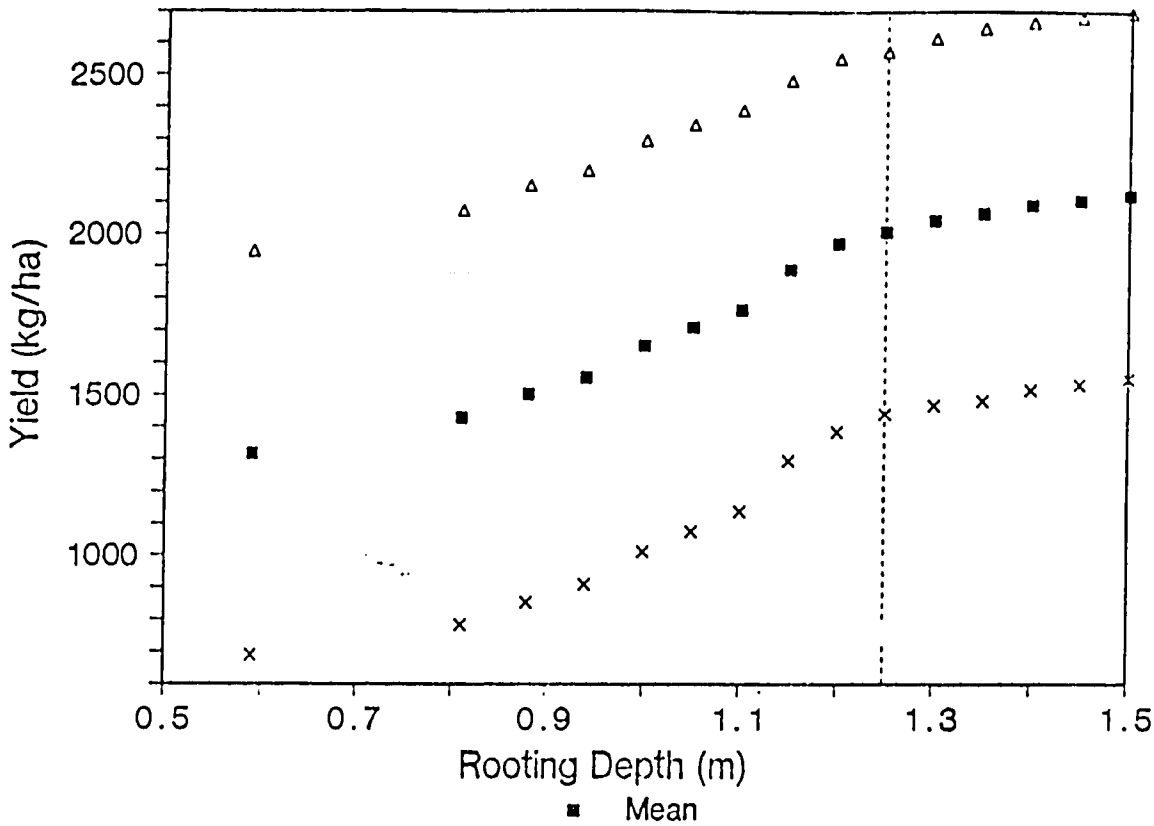


Figure 12. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).



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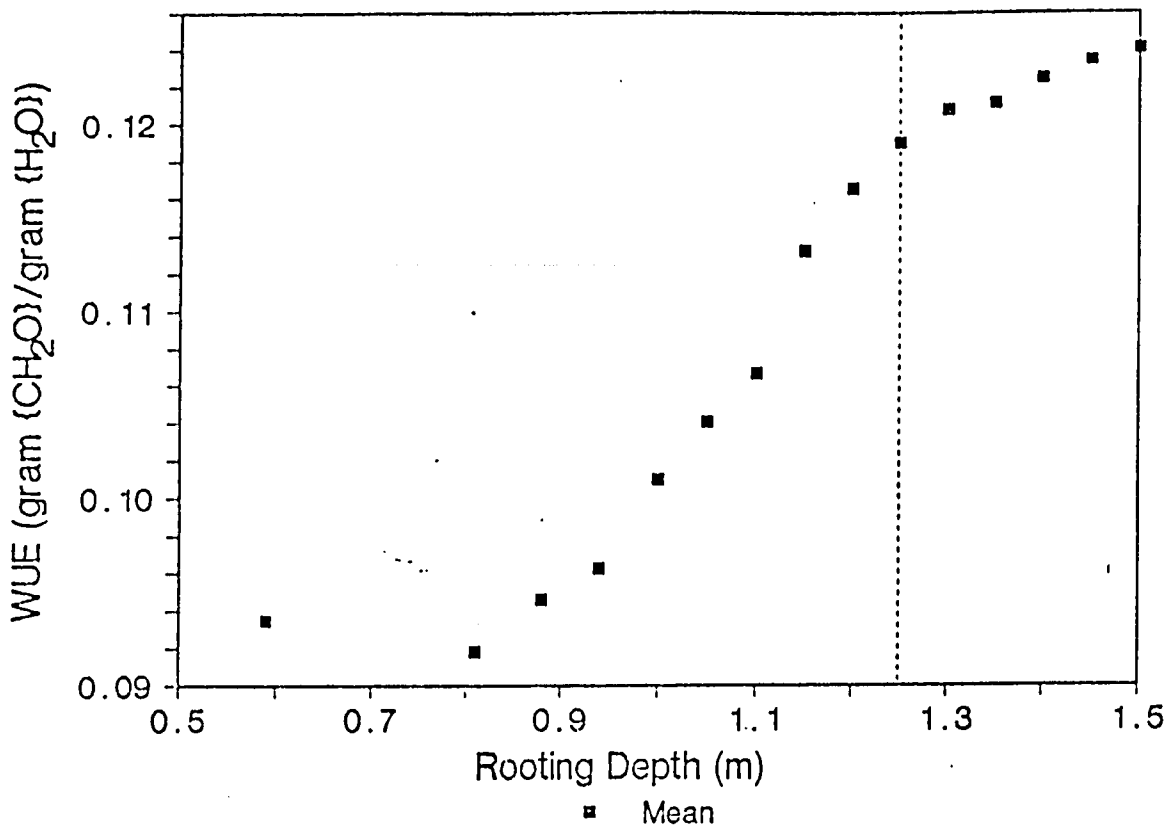

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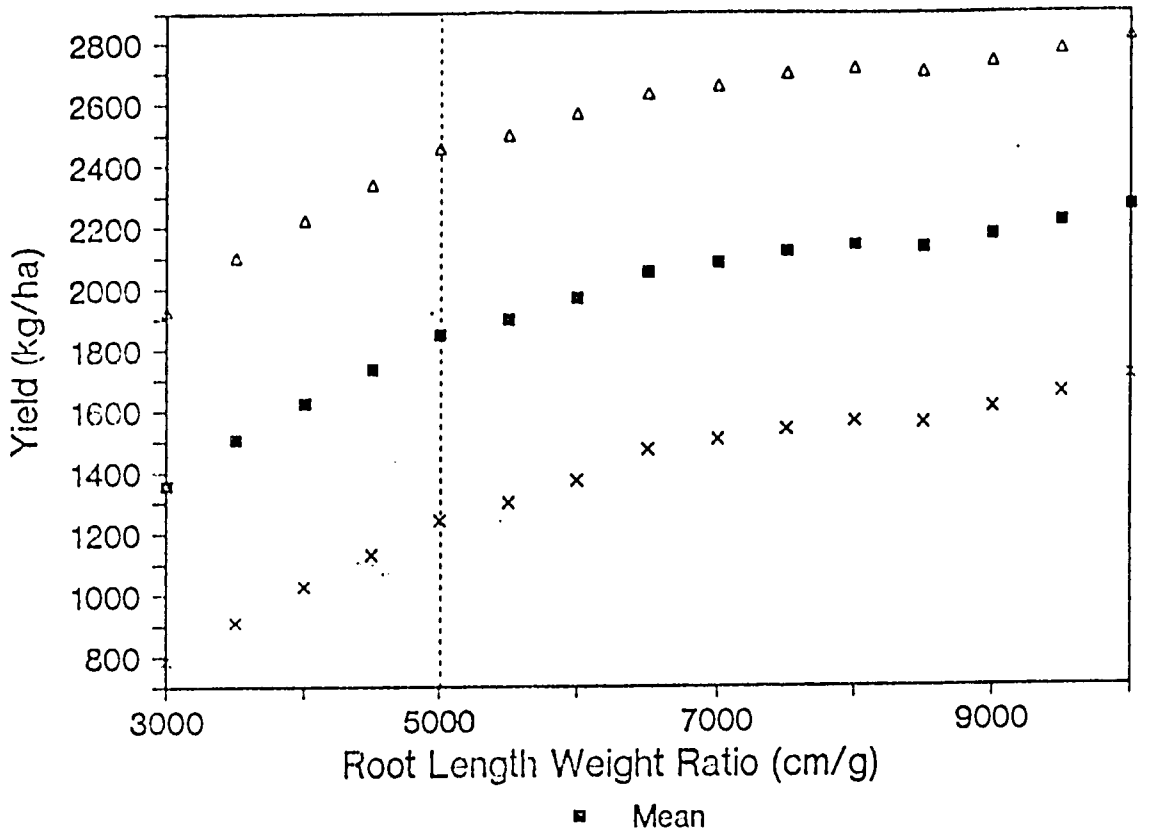

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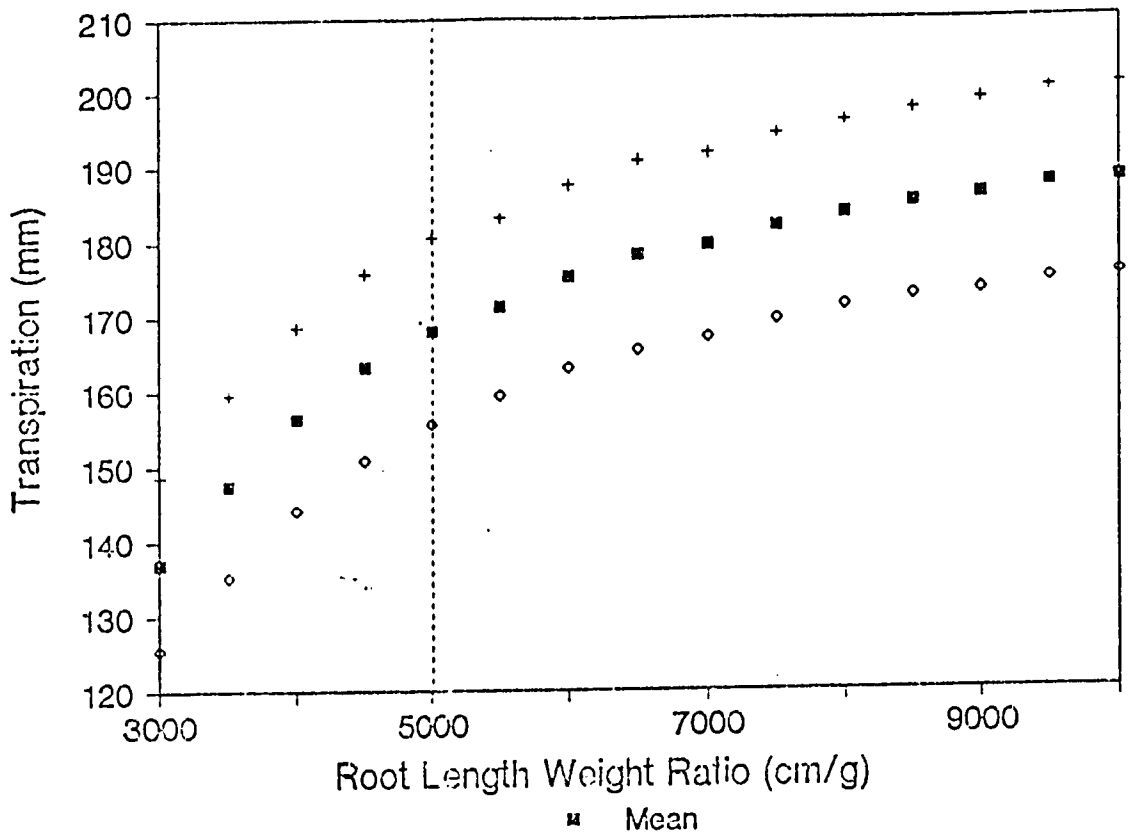

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