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# AGRO-CLIMATIC MODELING AS AN AGRICULTURAL RESEARCH TOOL

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# AGRO-CLIMATIC MODELING AS AN AGRICULTURAL RESEARCH TOOL

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## S U M M A R Y

The paper illustrates the use of an agro-climatic model so as to suggest agricultural research priorities. More generally, some of the main aspects of the modeling activity, as it is being conducted at EMBRAPA (the Brazilian Public Corporation for Agricultural Research) will be discussed.

## INTRODUCTION

In this paper we will try to illustrate the use of an agro-climatic model in connection with more traditional techniques, so as to suggest agricultural research priorities. More generally, the paper will consider some aspects of the modeling activity as it is being conducted at EMBRAPA (the Brazilian Public Corporation for Agricultural Research). The central idea with regard to modeling and simulation at EMBRAPA is that several feed-backs, acting upon the researchers and the research managers, can be obtained through these activities. This will help them to gain understanding about complex systems and set reasonable research priorities.

# THE USE OF SYSTEMS APPROACH AT EMBRAPA

The modeling activity is done within the general framework of the systems approach applied to agricultural research (ALVES 1975, DENT & ANDERSON 1971, DALTON 1975, SPEDDING 1979). In other words, it is seen as an essential component to the use of that approach. So, in order to place the modeling activity in its appropriate dimensions, we must review briefly some aspects of the systems approach.

Firstly, we must identify some systems that should be studied. Fig. 1 gives a short list of labels that can be attached to some of the systems that are of interest to EMBRAPA. Of course, these labels are not very descriptive; for instance, "PESTS" may refer to an insect-plant-water system whose description requires a lengthy paper. The important point to be stressed, is that we take farms ("farming systems") as the reference systems to be studied. All other systems, which may range from the whole country to a single animal, should be studied in relationship to the recommendations that must be given to the farmers. For instance, the study of an agro-climatic system, of the weather-soil-plant type, for the semi-arid region of Brazil, was considered essential in order to develop technologies that can be acceptable to the farmers.

Secondly, we must characterize some activities that should be carried out in order to use the systems approach. They are necessary, although by no means sufficient, if we want to claim that the systems approach is being used.

On one side, we have the traditional activities that can be roughly grouped into experimentation and sampling. They are essentially analytical, and have dominated agricultural research up to present days. On the other side, some new activities should be developed in parallel to the ones that have characterized the "experiment station". Here we include the use of mathematical (computer) modeling, the execution of case studies and the develop

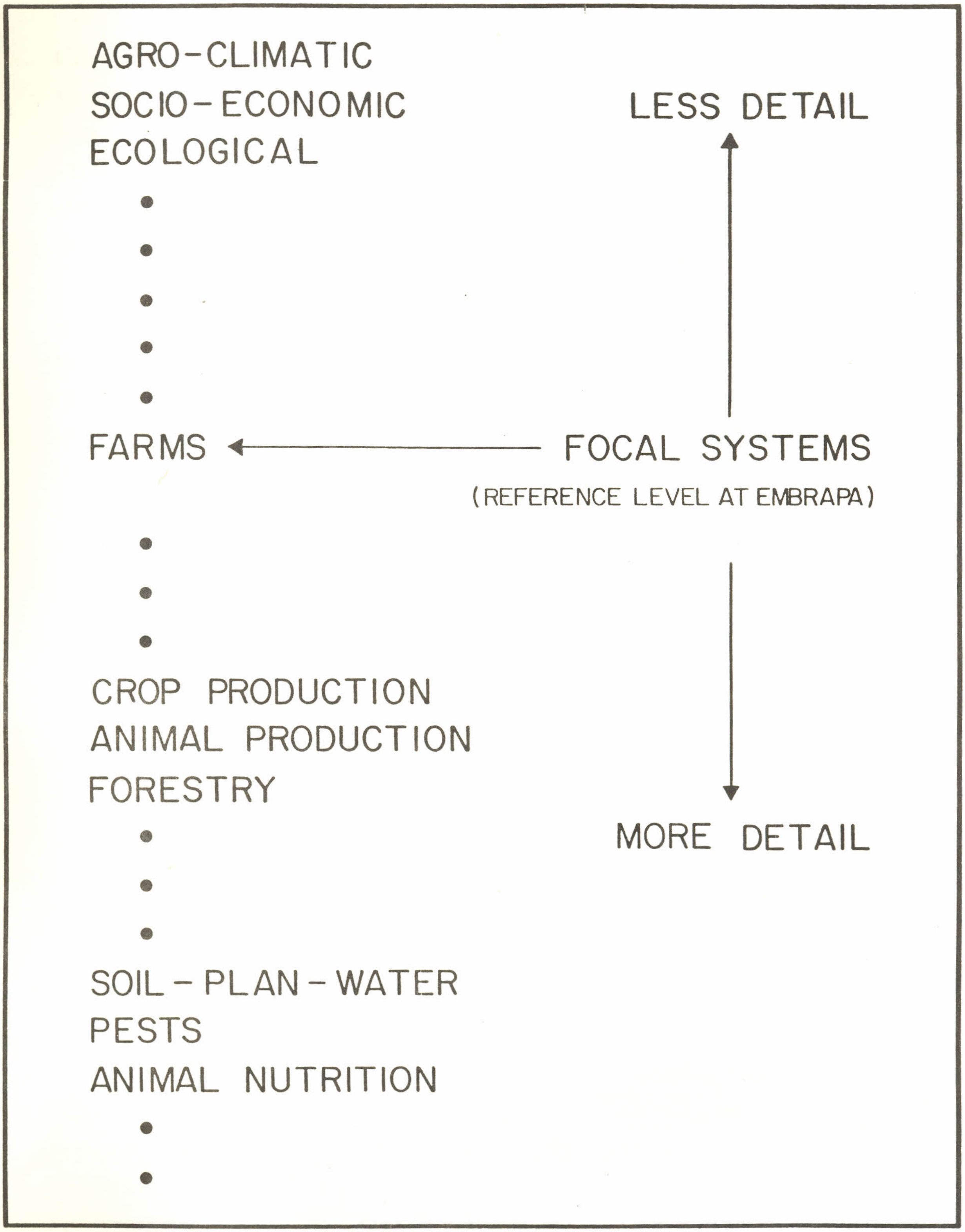


Fig. 1 - Examples of systems to be considered.

ment of large information systems (for instance, a climatic data base). These activities are essentially synthetic, at least in the obvious sense that they try to consider simultaneously a large number of variables together with their relationships. But, more than that, in connection with computer models and case studies, a conscious effort is made to study not only how but also why the system works the way it does. This is a central aspect of the systems approach, which requires synthesis rather than analysis (ACKOFF 1979a, 1979b). In this context, synthesis means not only the combination of the different components of a system, but also the consideration of larger systems, that contain the one we are interested in. For instance, to study farming systems in the semi-arid tropic of Brazil, it was considered necessary to study an agro-climatic system at the county level; also, the study of some other systems, containing economic, marketing and employment aspects will be required. For example, if an agro-climatic or a farm management model indicates that the best thing is to plant mellons and most farmers in a region follow this recommendation, the result may be an economic disaster.

## THE ROLES OF MODELING AND SIMULATION

In this section, we will discuss the main functions that we associate to the modeling and simulation activities, within the research environment of EMBRAPA. At this stage, it is assumed that a group of researchers has identified an important system, and that they are willing to allocate a substantial part of their time to its study.

We can take as an example a water-soil-plant system, that can be common to many farmers in a given region. Tipically, the researchers have some knowledge and biological data relevant to the study. The data were obtained through the use of traditional techniques, applied within the work of specific disciplines(plant physiology, soil physics, water management, etc.). We are not referring here to the climatic data that have been recorded over the years. Later on we will comment on the availability of climatic data.

Suppose that it is found that a mathematical(computer) model would be useful to understand how and why the system works the way it does, and how it could be changed or controlled. First, we note that the model is not an end in itself, but a means to gain understanding. Second, as soon as we start the job of building the model, most probably with the help of a modeling expert, a first feed-back, acting upon the researchers, appears very clearly. This is indicated by (1) in Fig. 2. In fact, it is found very soon that the available knowledge and data are not enough to build the model. The researchers must perform several activities, like reviewing the literature, formulating new hypotheses and holding discussions with other scientists. Besides that, the original multidisciplinary team starts to work in an interdisciplinary way, so as to combine the points of view and the techniques of several disciplines (BIRNBAUM 1979,PAYNE 1979).

Then, suppose that, with the available information, we are able to formulate a mathematical model. At this stage, a second feed-back (indicated by (2) in Fig. 2) can be activated through the use of simulation. In this paper, the word simulation is used in the sense of numerical experimentation. It includes parameterization and sensitivity studies, performed with the model.

The simulation exercise can indicate some points where more research is necessary, together with some others where the available knowledge should be considered satisfactory. Besides that, it may point to several weaknesses in the model, so that some corrections should be made.

The two feed-backs described above are the most important, at the present stage of the modeling activity at EMBRAPA. Depending upon the system under study and the available model, some other feed-backs can be activated. For instance, we can show the model outputs to external experts, extension agents or farmers, and ask them to criticize the results. But, in general, at the present stage, our models are not intended to advise the farmers directly; they are rather considered to be research tools.

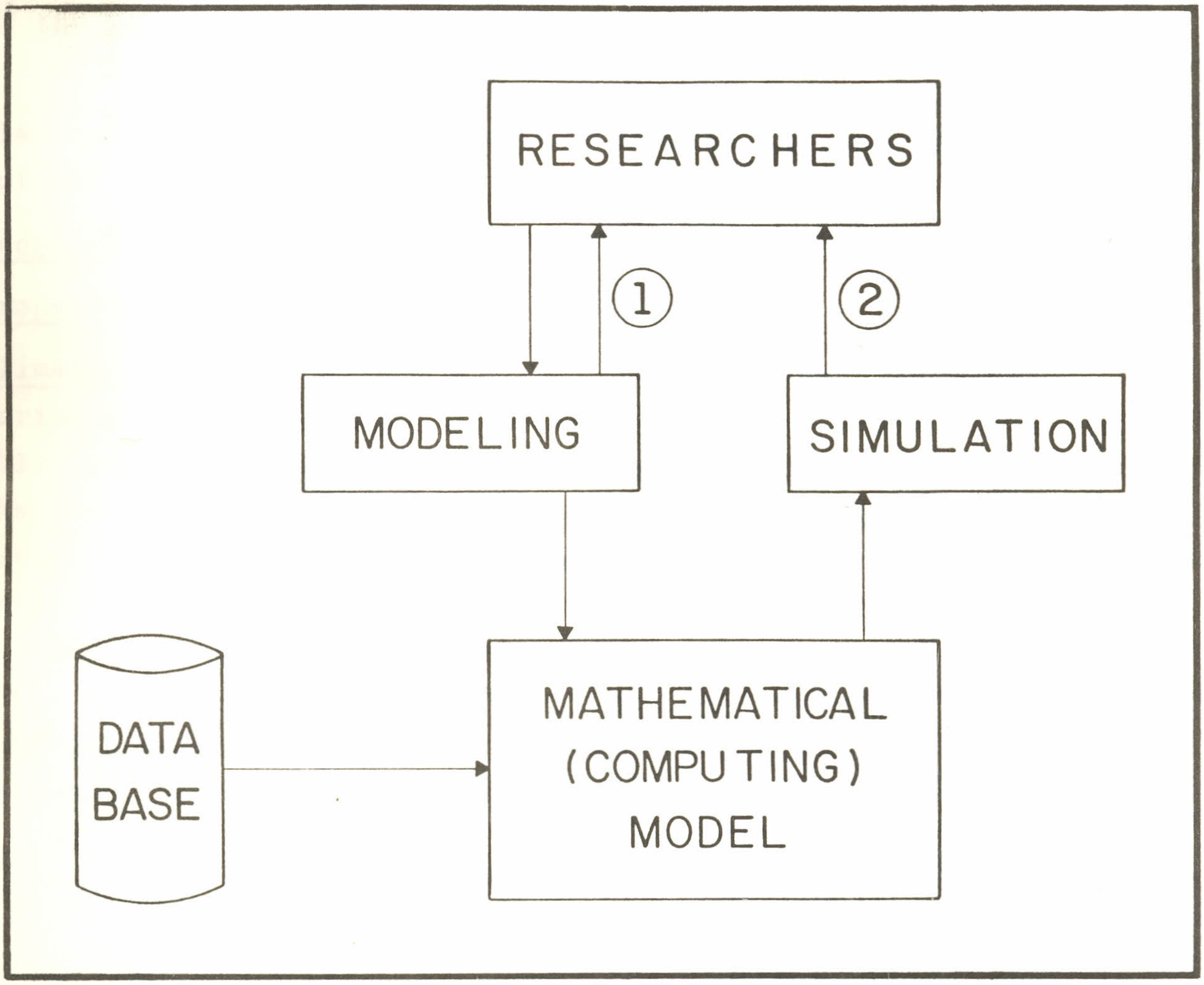


Fig. 2 - Two main feed-backs produced by modeling and simulation.

# OUTLINE OF AN AGRO-CLIMATIC MODEL

In this section we will present an overview of an agro climatic model for the semi-arid tropic of Brazil. A detailed description will be published elsewhere. Here, only a summary of the main aspects, illustrated in Fig. 3, will be given.

The system is of the water-soil-plant type. For each planting period and for each year a water balance is carried out and the productivity is estimated.

Geographic boundary. A county with meteorologic station.

Crops. Only annual crops are considered.

Climatic data. The model requires daily rainfall data for a series of years (tipically, between 20 and 50 years are available) and mean monthly temperature and relative humidity. In the present version, solar radiation and potential evapotranspiration are calculated with formulae proposed by Hargreaves, that make use of the temperature and relative humidity data and take into account the latitude of the meteorologic station. The computer program, written with small modules, is very flexible, so that different routines may be used, in the future, to estimate potential evapotranspiration.

Soil. Water holding capacity is estimated for the most frequent type of agricultural soil in the county.

Plant. Root development is estimated for the crops of interest (mainly corn, beans and sorghum), for the chosen type of soil. Evapotranspiration coefficients are estimated or, else, taken from the literature.

Simulation step. The user specifies the length of the planting period (tipically, 5 days). If one chooses 5 days, the year is divided into 73 periods. Then, the daily rainfall and potential evapotranspiration values are grouped into five days values.

Productivity. For each planting period and each year, the model estimates the productivity (defined as the ratio between actual and potential production) as a function of water stress. Differ

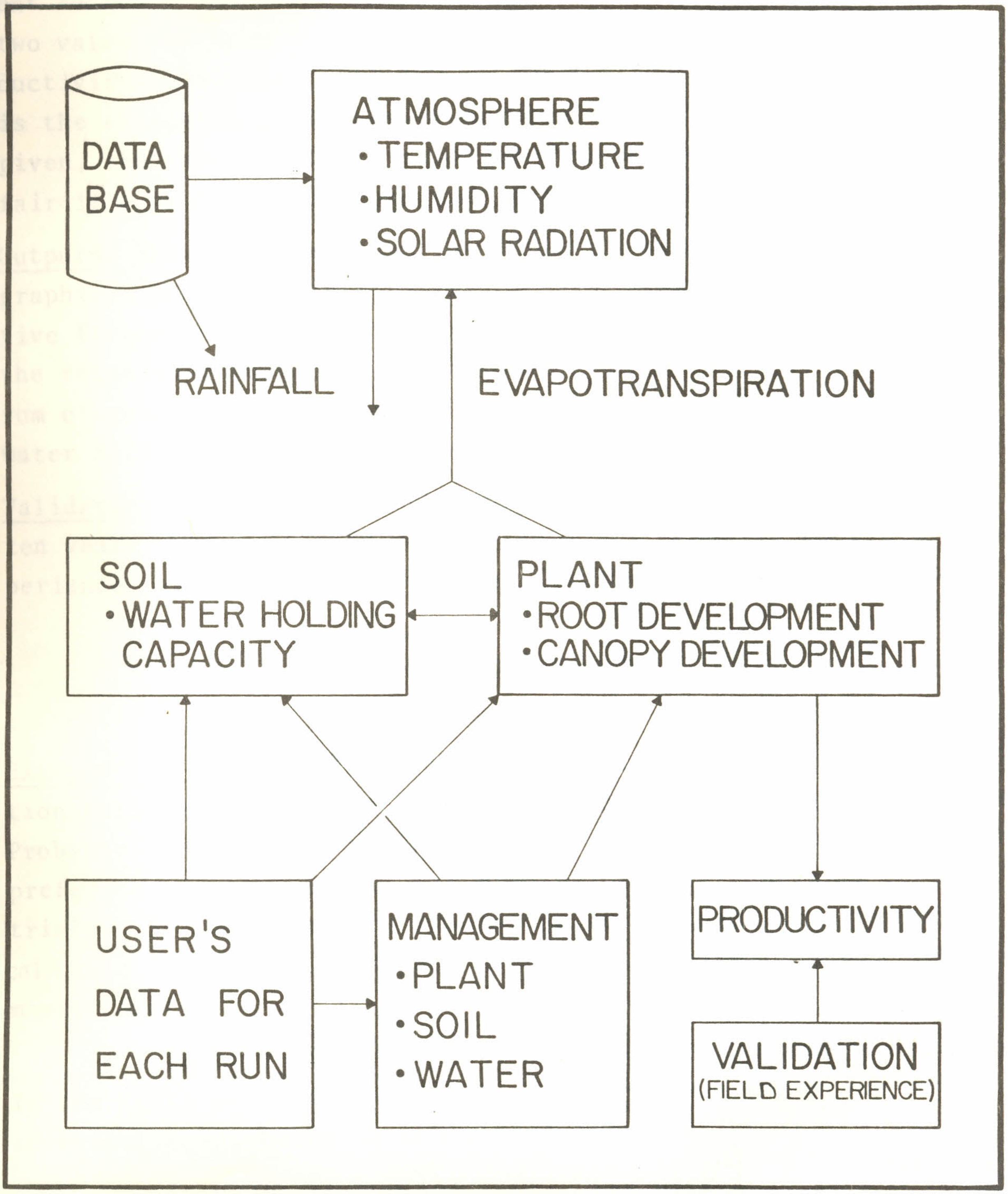


Fig. 3 - Basic components of an agro-climatic model for the semi - arid tropic of Brazil (annual crops).

ent response functions can be easily tested. The user must give two values between 0 and 1, so as to classify the estimated productivity into "good", "fair" or "bad". For instance, if PROD is the estimated productivity and the values 0.8 and 0.5 are given, then the result is considered to be good if PROD $\geq$0.8, fair if 0.8> PROD $\geq$ 0.5 and bad if PROD <0.5.

Outputs. The computer gives two kinds of outputs: numeric and graphic. For each planting period, the program gives the relative frequency of good, fair and bad productivity results (also the relative frequency of "acceptable" results, defined as the sum of good and fair ones, is printed); mean runoff and mean water deficit are also printed. These same values are plotted.

Validation. The model results corresponding to each of the last ten years with available weather data are compared to field experience, with the cooperation of farmers and extension agents.

## USE OF THE MODEL

Example 1. We will illustrate the use of the model with a simulation that takes the form of a traditional 2×2 factorial experiment. Probably, most people would say that we run four simulations. We prefer to say that we run one simulation that consisted of four trials. So that the term simulation corresponds to a hypothetical field experiment, and each trial is equivalent to one experimental plot.

In this first example, we consider the county of Irecê, in the State of Bahia. This is the main beans producing county in Brazil; so, beans is the chosen crop.

In order to run the model, the user must give a set of evapotranspiration coeficients ($k_c$) and a set of yield response factors ($k_y$). Now, we have two sources for these sets of values: we can take them from the literature or we can use the values estimated by our researchers. So, we have four combinations that take the form of a 2×2 factorial experiment.

Here, for convenience, we will indicate with FAO the values given by DOORENBOS & KASSAM (1979), and with EMBRAPA the values estimated by EMBRAPA's researchers at the Center for Agricultural Research of the Semi-Arid Tropic (CPATSA). Table 1 gives a summary of some of the results printed by the computer.

TABLE 1. BEST PLANTING INTERVAL AND PERCENTAGE OF YEARS WITH ACCEPTABLE YIELD
(County: Irecê. Crop: Beans)

| YIELD RESPONSE FACTORS ($k_y$) | CROP EVAPOTRANSPIRATION COEFFICIENTS ($k_c$): F A O | CROP EVAPOTRANSPIRATION COEFFICIENTS ($k_c$): EMBRAPA |
|---|---|---|
| FAO | Oct 23/Oct 27<br>62% | Oct 13/Nov 6<br>62% |
| EMBRAPA | Nov 7/Nov 11<br>35% | Nov 7/Nov 16<br>35% |

Conclusions. Several conclusions can be deduced from the study of the computer output . We list here a few of them.

(1) The best planting season lies in late October and early November, in agreement with field experience.

(2) A chance of 35% of years with acceptable yield, which means one out of three years, is much closer to field experience than the 62% value.

(3) The model is very robust with regard to $k_c$ values, for anyone of the two sets of $k_y$ values.

(4) The model is very sensitive with regard to $k_y$ values, for anyone of the two sets of $k_c$ values.

Recommendations. Several recommendations can be submitted to the researchers, so that they can be in a better position to set reasonable priorities for their work. Of course, the ultimate decision may depend on several factors not included into the model or completely independent of the system under study (for instance, the availability of personnel or equipment). We list here some of the recommendations submitted to the researchers; these recommendations are valid for the county of Irecê.

(1) Do not plan any "best planting period" field experiment, since the model already gives reasonable and robust results.

(2) Give high priority to the study of different water stress response functions. Plan some experiment where the plots are submitted to different levels of water stress at different stages of the plant cycle. Meanwhile, in other simulations, use the $k_y$ values estimated at CPATSA, since the results they give are close to field experience.

(3) Give low priority to any new estimation of the $k_c$ values; the values in the literature should be considered satisfactory for the time being.

Example 2. The county of Santana do Ipanema, in the State of Alagoas, is also in the semi-arid tropic of Brazil, but differs quite clearly from Irecê with regard to dominant soils and rainfall distribution. A simulation analogous to the one in the previous example was performed for the county of Santana do Ipanema, where 57 years of rainfall data were available. Besides the rainfall data, the other difference with the first example lies in the root development data; in fact, the model requires this information in order to relate the type of soil with the plant. Table 2 gives a summary of the results for this exemple.

TABLE 2. BEST PLANTING INTERVAL AND PERCENTAGE OF YEARS WITH ACCEPTABLE YIELD

(County: Santana do Ipanema. Crop: Beans)

| | | CROP EVAPOTRANSPIRATION COEFFICIENTS ($k_c$) | |
|---|---|---|---|
| | | F A O | EMBRAPA |
| YIELD RESPONSE FACTORS ($k_y$) | FAO | May 26/May 30<br>86% | May 21/May 30<br>86% |
| | EMBRAPA | May 26/May 30<br>81% | May 26/May 30<br>79% |

From the examination of the computer output, summarized in Table 2, we conclude that the results are very robust with regard to different sets of $k_c$ and $k_y$ values. Therefore, for the time being, we do not see any urgency to repeat the field experiments in order to improve our estimates of the $k_c$ and $k_y$ coefficients. In other words, the model suggests that this sort of field experiments has low priority in that county.

<u>Example 3.</u> The irrigation specialists at CPATSA have developed or adapted some water management technologies, that could be of great help for the small farmers. These technologies are based on the storage of runoff water to be used in shortage periods. They understand that there already exist some technologies that could give a high yield, if the farmers could store at least 100 millimeters of

runoff water. The model shows that, in all the counties already studied, there are several periods with runoff well above the 100 millimeters mark, in a large percentage of years. On the one hand, this confirms the hypothesis that the main problem is not the lack of water, but the uneven distribution of rainfall. On the other hand, these results show that EMBRAPA can disseminate those technologies among the farmers, and expect a high chance of successs; but, before doing that, the upmost priority should be given to the feasibility analysis of the proposed technologies at the farm level. So, if we consider the individual disciplines involved, the priority shifts from water management (which developed or adapted the technology) to farm management and economics (to see if the technology can be acceptable to the farmers).

## CONCLUDING REMARKS

The central idea of this paper was to present the use of an agro-climatic model as an illustration of the general approach followed at EMBRAPA with regard to modeling and simulation. A similar account could have been illustrated by means of other models (for instance, pest control or cattle management models). In any case, the work on agro-climatic modeling is probably the best example to give a thorough picture of the present situation with regard to modeling and information systems at EMBRAPA.

On the positive side, we can list the following aspects:

(1) A reasonable know-how has been gained with regard to the development and maintenance of computer models. Once an initial characterization of the system to be studied has been given, a first version of the mathematical model and the corresponding computer program will be ready in a few weeks. Since both the model and the computer program are subject to frequent changes, the main concern shifts from formulation to maintenance. Therefore, a central importance is being given to modern programming techniques (mainly top-down, modular and structured programming), so as to simplify the maintenance work.

(2) There is a large amount of climatic data. In fact, many stations have collected these data for more than sixty years, which places Brazil in a very good position to undertake climatological studies.

(3) EMBRAPA's researchers are very interested in using computer models. The experience has made it clear that computer technology offers, perhaps, the only possibility to study many complex systems.

(4) EMBRAPA's expanding computer installation is among the bests in Latin America in the field of scientific data processing.

On the negative side, we can mention two problems that will certainly receive much attention in the near future:

(1) An on-line climatic data base is not available. For the most part, the weather data are still in sheets and books, scattered throughout the country. So that, although all kinds of climatic models can be quickly developed, they can not be put into operation because the data are not readily available for computer processing. In other words, the modeling know-how is far ahead of the availability of the information systems required to use the models.

(2) Most research stations do not have as yet remote terminals, linked to the central computer, due to telecommunication problems. This is the case, for instance, of the Center for Agricultural Research of the Semi-Arid Tropic. Therefore, computer processing is done at headquarters and the outputs are mailed to the researchers. As it can be expected, this creates considerable difficulties to the use of computer modeling.

Once these problems are solved, the use of computer modeling and information systems in connection to agro-climatic studies will become a matter of routine. But, in the meantime, even with the difficulties mentioned above, models are already being used at EMBRAPA to set some research priorities. For instance, the model presented in this paper had a significant impact on project formulation during the last Annual Programming Meeting (August, 1981) of the Center for Agricultural Research of the Semi-Arid Tropic. Several field experiments, with different crops, will include the measurement of the parameters required by the model (among these, root and canopy development, length of the various phases of the plant cycle, plant response to water stress, etc.), even though these measurements were not among their main objectives. Thus, several researchers have clearly understood that they can use the model to save time in their future work.

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