SIMULATION REPORTS CABO-TT NO. 2

MODELING OF CROP PRODUCTION: EVALUATION OF AN INTERNATIONAL POST GRADUATE COURSE HELD AT IDEA, NOVEMBER, 1982

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Origineel

INSTITUTO INTERNACIONAL DE ESTUDIOS AVANZADOS 1983

Simulation Reports CABO-TT

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Given the importance of the selected topic of the course and due to the high priority assigned to agricultural development and specially in the third world, IDEA received important contributions from international organizations as UNESCO, OEA and OPEC, which were used to cover the travel expenses, room and board of 20 students.

2.- GENERAL CHARACTERISTICS OF THE COURSE.-

2.1 Objectives: The main objectives of the course were to introduce the concept of Dynamic Simulation and to describe, in a quantitative manner, the most important processes which determine crop growth and its interaction with the environment. Participants should not only receive theoretical insight into this matter, but also obtain some practical experience. The course was addressed to biologists, agronomists, agricultural engineers or any other related professionals.

2.2 Participants:

The criteria of candidates selection were the following:

i) Educational background and some years of practical work in biology, agronomy or any other related career.

ii) A citizen of a third world country.

iii) Experience or research activities related directly or indirectly to mathematical modeling of crop production.

iv) Distribution of scholarships among countries and institutions of each country.

Participants included 18 Venezuelan professionals and 19 professionals from 13 other countries of the third world. Appendix 1 gives a list of their names and addresses and those of the lecturers. Of the participants, about half had any previous experience with a computer and almost none with modeling. While all participants could read English, only about half spoke it.

2.3 Organization:

The course was organized by Professors: L. Villegas, L. Bascones and J. Córdova of IDEA, and Professors: F. Penning de Vries and H. Van Laar from CABO and AU respectively, of Wageningen, The Netherlands.

As text book was used: "Simulation of Plant Growth and Crop Production" edited by the Professors Penning de Vries and Van Laar. The book was written by several professors of AU and CABO as part of a similar course held during the spring of 1981, at Wageningen. In addition to this text, a series of other references were used as complementary material for the course. A list of these references is included in Appendix 2.

The general program of the course was developed following the outline of the textbook, with some modifications in the practical portions of the course. The case studies dealt with tropical crops under tropical weather and soil conditions. Besides, three lectures given by national and international researchers with experience on simulation of tropical crops were included as special evening sessions of the course.

The course was organized in three blocks:

I.- Introduction to dynamic simulation and the use of elementary calculus.

II.- Crop growth simulation under optimal conditions using a summary model.

III.- Crop growth with limiting factors like water and nitrogen, or with pests and diseases attacking the crop.

The course was held in two weeks (10 working days) with the cooperation of six professors of the Agricultural University and the Centre for Agrobiological Research, Wageningen, two professors of the Simon Bolívar University of Venezuela and one professor of the "Centro Internacional de Agricultura Tropical", of Colombia, for one week. The format of the course was such that during the morning hours theory classes were held, and the afternoon were dedicated to practicals with textbook exercises and case studies, including "hands on" experience with the computer. The course program is presented in Appendix 3. On the Saturday during the course, an excursion was held to FUSAGRI and the Maracay experiment station.

The case studies were solved using IDEA's PDP-11/23 computer, with nine VT-100 terminals and one printer. Due to the limited capacity of this equipment, it was impossible to use the language of simulation described in the text book, called CSMP (Continuous Modeling Simulation Program). A similar, but simpler computer language, DARE-P, was used which permitted the solution of most examples and exercises in the textbook. DARE-P was created to work in similar computers to the one actually available, and is therefore accessible to may more people than CSMP which requires still a main frame computer. In Appendix 4, the principal differences between CSMP and DARE-P are presented.

3.- TECHNICAL EVALUATION OF THE COURSE.-

At the end of the course, the participants were asked to fill out an evaluation form which gave us the following information.

About 49% of the participants considered that the two weeks duration is the most appropriate length. If the length of the course had been 30 days, only 40% of the students would have participated.

A hundred percent of the participants considered useful to repeat the course within the next two years, including, if possible, the use of advanced methods in modeling.

With respect to the course structure, the interest of the participants was similar in the three blocks, (see section 2.3) with somewhat more interest on block III. The participants considered that blocks II and III offered the most information as for new techniques of analysis and a greater practical experience.

The classes given by each professor were evaluated in an individual manner having an average result of 77 points over 100 with a standard deviation of 12 points.

Seventy three percent of the participants felt that the ratio lectures-exercises, was appropriate and that supervision during the practical exercises was suitable. However, almost 100% of the participants were of the opinion that additional time for practices was needed in order to finish their exercises, even though many evenings were used for practicals.

Almost half of the participants considered that the instructions given for use of the terminals and the language DARE-P were not enough. This may be a reflection of the fact that almost none of the participants had experience working with computers like the PDP-11/23.

For 71% of the participants the simultaneous translation (English-Spanish) during the lecturers was indispensable. There was no translations facilities during the exercises, but 66% thought that it would have been useful.

The textbook used during the course was found to be difficult but clear by 60% and "easy" by 30%. More or less the same applied to the exercises.

Finally, the general evaluation of the course was "excellent" by almost the totality of the participants.

4.- CASE STUDIES.-

4.1 The Groups:

The participants were subdivided into 8 groups of 4 persons on the second day of the course, such that each group had at least one person with experience in using a computer and at least one spoke English. About half of the group re-organized themselves later that week, and one group was reconstituted anew once more before the case studies started. A ninth group was formed from late arrivals, and did not address itself to a specific crop or situation. Reasons for regrouping were that few personal or professional contacts existed between participants before their arrival, and that their interests were not always clearly defined and sometimes changed as the course proceeded.

On Monday and Tuesday of the second week, discussions were held with each group to delineate a case to be studied for the remainder of the course and to formulate the goals to be reached. It was the aim to establish objectives that could be completed within the limited time span and that addressed fairly realistic questions in the field of expertise or interest of the group members. This implied adaptation of one of the models presented during the course (SUCROS plus water balance) and its application to a certain crop in specific climatic and soil conditions. The cases are presented and the results are discussed briefly below to demonstrate the skills attained by the participants in this course.

Most participants did not bring own crop, climate or soil data. We had to rely therefore, in particular, on weather and soil data about Venezuela and on crop characteristics previously collected in Wageningen. Those weather data concerned Maracay, a city in North Venezuela with a distinct humid and dry season (annual precipitation 1000 mm) and El Cují in the South West of the country without a distinct humid period and with an annual precipitation of about 400 mm.

4.2 <u>The Starting Point</u>:

SUCROS (a simple and universal crop growth simulation, Penning de Vries and Van Laar, 1982) is a relatively simple program to simulate the growth of a field crop. It has been utilized intensively in the course. It is a summary model: most of its parts can be expanded into more detail and accuracy if need arises. The model concerns only growth in conditions without shortage of water or nutrients, and in pest and disease free conditions. The parameters and functions in the program, as it is presented in the textbook, are those for wheat production in Zambia. A simple water balance, based on some of the Chapters of the textbook, was added to SUCROS during the course.

SUCROS calculates the rates of photosynthesis, respiration and growth of dry weight and of leaf area on a daily basis, as a function of the current state of the crop and of the weather. Partitioning of the daily dry matter increment over leaves, stems, storage organs and roots occurs as a function of the physiological age of the crop. The effect of photoperiodism on physiological aging is included in SUCROS, but was eliminated in all case studies for lack of specific data.

The soil water balance section concerns infiltration, evaporation and transpiration of water as a function of weather conditions, the state of the crop and of soil water content. The water content of three horizontal soil layers is simulated. Roots may grow into these layers and absorb water from them. The growth and water balance sections are linked: the rate of transpiration equals the photosynthesis rate times a water use efficiency factor if plenty of water is present, and photosynthesis equals the transpiration rate divided by this factor in case of water shortage.

4.3 Group Reports:

The notes below are based on the written short reports of the groups, made in the last afternoon. The 'remarks' added below are observations by the authors of this report.

4.3.1 Group 1.-

Objective: To estimate the amount of water needed for optimal growth of sugar cane in Cuba on fertilized soil with and without irrigation.

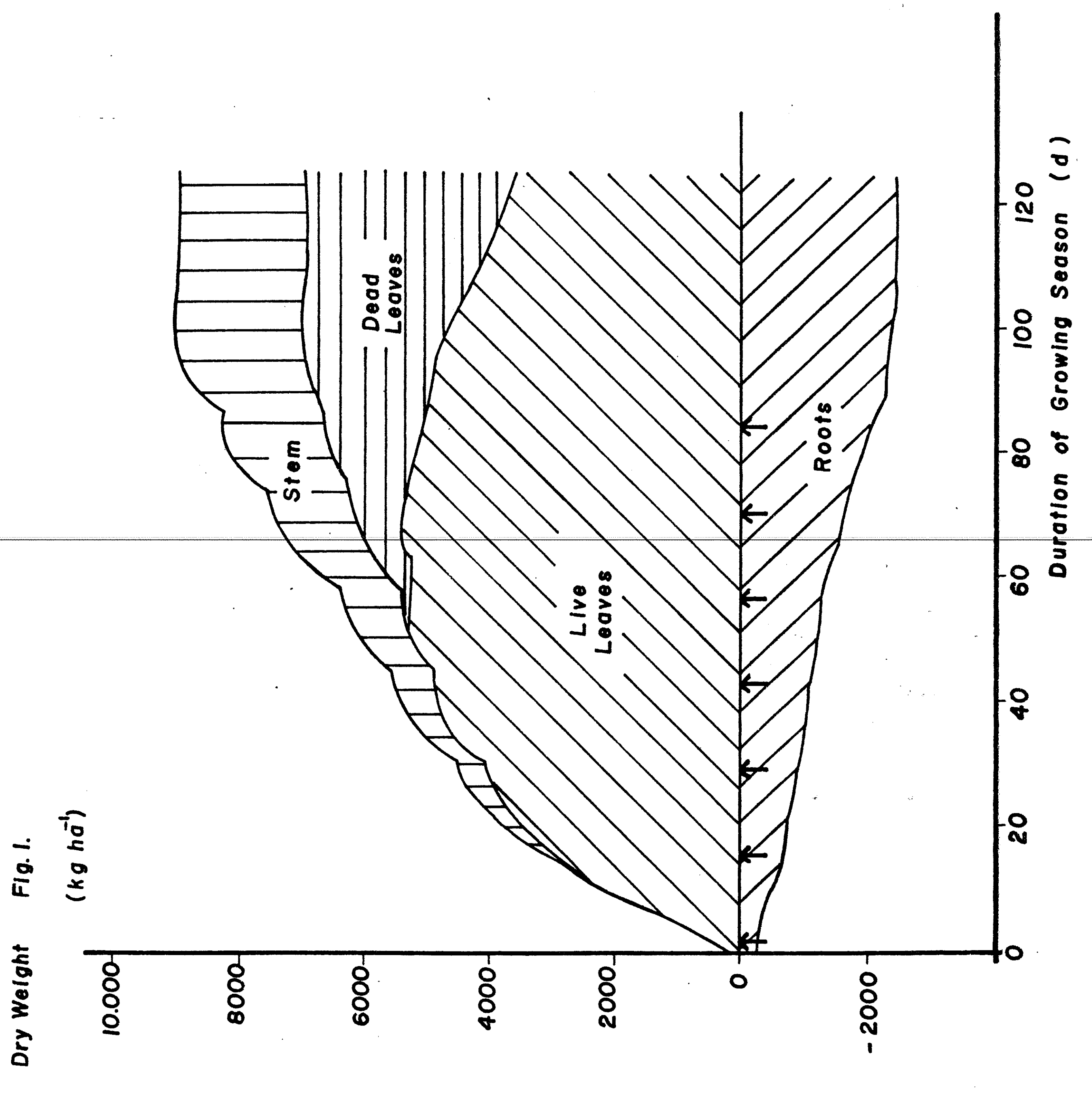
Actions taken: The dry matter distribution function in SUCROS was replaced by one suitable for the sugar cane crop, in which the dry matter distribution was expressed as a function of time. The storage organ as such was suppressed, but a certain percentage of sugar in the stem was simulated instead. This percentage was programmed to be correlated negatively to temperature. Other parameters were also chosen to represent a sugar producing C_4 species. Monthly averages of weather data for Cuba were approximated. The program was run for 12 months.

Results: It took almost to the last minute to get a running program as typing and programming errors kept popping up. The output showed a young crop that grew vigorously in the beginning, but slowed down later as irrigation (50 mm per two weeks) did not compensate for the high evaporative demand (up to 10 mm d^{-1}). Figure 1 illustrates this clearly. When irrigation stopped after 7 cycles, the crop ceased to grow almost immediately. Time did not permit to improve this irrigation scheme and to study its results.

Remarks: In an earlier stage, the question was posed how wheat would perform in Cuba. The standard model, parameterized for wheat, was then supplemented with a temperature response of photosynthesis (reduction above 30°C), and monthly averages of Cuba radiation and temperature were introduced. The simulated results indicated that in the dry season, with irrigation, wheat would yield about 1300 kg ha^{-1} of grain. In the wet season with less radiation but also without need for irrigation, it yielded only 1000 kg ha^{-1}. In this way, the model confirmed agronomic experience not to grow wheat in Cuba's lowlands.

Figure 1

The growth of a sugar cane crop, of which the major organs are distinguished, in an irrigation scheme: 50 mm of water each 2 weeks (arrows).



4.3.2.- Group 2.-

Objectives: To evaluate the growth of natural grassland vegetation in semi-arid conditions in Venezuela.

Actions taken: The grassland consists primarily of perennial grasses with a long growing season. Proper parameters and functions were chosen to represent this crop. The initial biomass is quite high; about 9300 kg ha^{-1} of roots and 15500 kg ha^{-1} of above ground dry matter has been observed. These high values caused a technical problem with DARE-P which was solved ultimately. The water balance was adapted to conditions of El Cují.

Results: In discussing objectives, it had been overlooked that the grassland is inundated (by runon water) for a few months at the end of the growing season. This phenomenon became only obvious after confronting the simulated growth curve with field observations. Hence the modeling effort appeared helpful in correcting and improving the description of the topic. If conditions had been such that inundation did not occur, production would have been as shown in Figure 2.

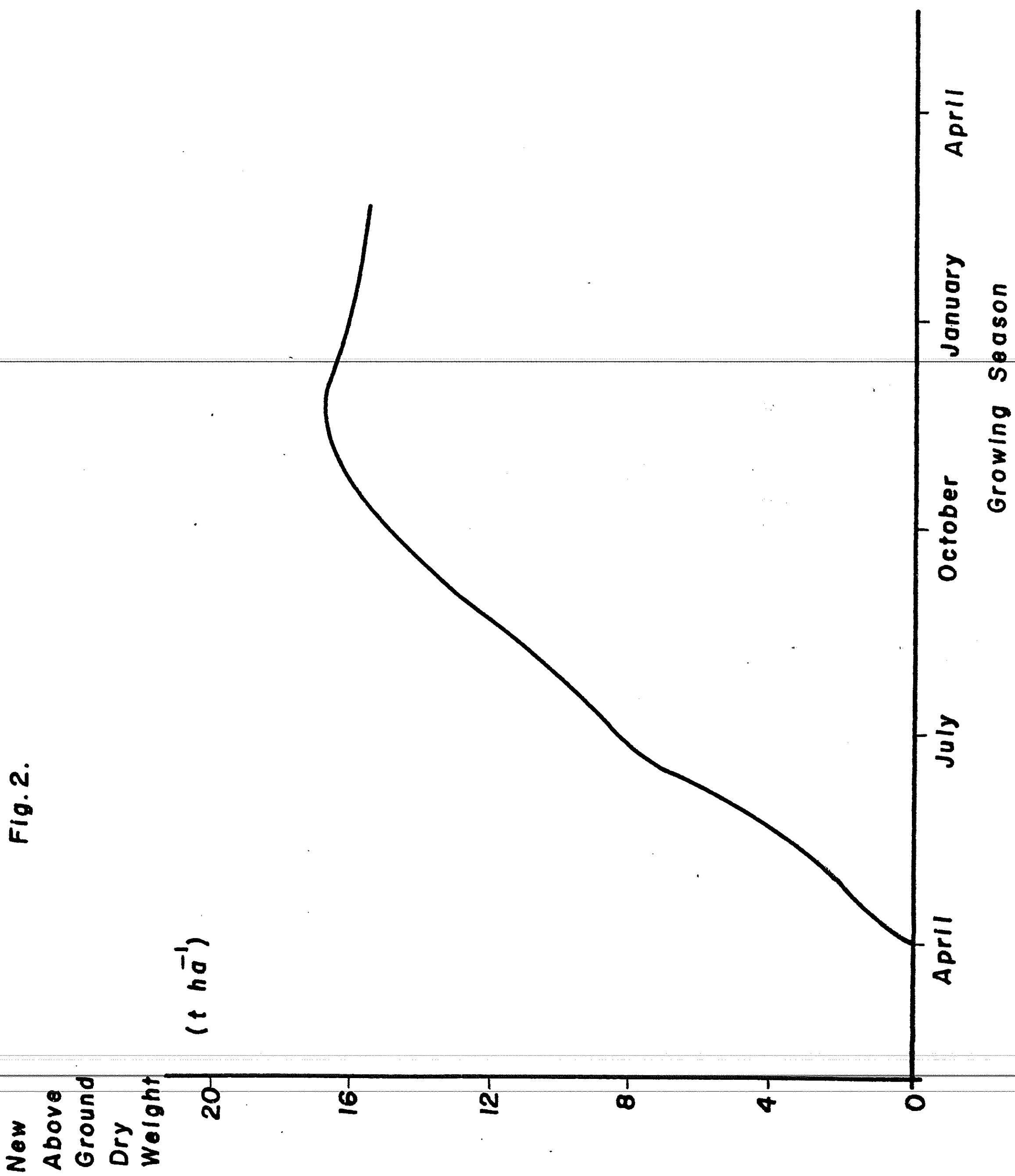
Remarks: This group had no language common to all of them, which slowed down its progress.

4.3.3.- Group 3.-

Objectives: (a) To analyze the effect of temperature variations on the yield of grain maize in Maracay weather conditions with optimal soil-water and ample fertilizer,(b) to evaluate the effect of water shortage on growth of this crop with a simple risk

Figure 2

The development of the biomass of a natural grass vegetation during the growing season as simulated without inundation.



analysis.

Actions taken: SUCROS plus water balance was parameterized for maize in the conditions described. The maize crop was simulated to be planted May 15th at a density of 40.000 plants ha^{-1}, flowered July 14th and was mature September 17th. Then, the model was run for completely clear and completely overcast skies to establish the very extremes of potential yield without any water stress. As compared to normal weather conditions: grain yield appear to double or halve, respectively, in response.

With the water balance effectively simulated, a simple risk analysis was performed by simulating conditions with an increased precipitation (by 50%) and decreased radiation (by 10%) from 30, 60 and 90 days after planting onwards, and also by simulating the inverse situation of less rain and more radiation. Potential evapotranspiration was estimated at 75% of the Penman evapotranspiration given in meteorological tables. It is known that the period around flowering is more sensitive to water shortage; this effect was not included for lack of time.

Results: Some of the results are presented in Table 1. Drought reduces biomass particularly in cases of a long period of reduced rainfall. Hence most of the effect is on the grain yield. The more humid period yielded also less:the radiation level dropped.

Table 1. The effects of modifications of the radiation and precipitation level on production of a maize crop. Yields are expressed as a percentage of the yield potential under normal weather conditions in Maracay, Venezuela.

	total biomass	grain yield
normal conditions	100 (17093 kg ha^{-1})	100 (9055 kg ha^{-1})
continuously fully overcast	55	53
continuously fully clear	186	176
'dry' after Aug 15th	99	99
'dry' after July 15th	82	66
'dry' after June 15th	45	9
'humid' after Aug 15th	96	92
'humid' after July 15th	83	68
'humid' after June 15th	49	15

It was remarked that simulated yields exceeded those of experiments in similar conditions, probably in particular because ample fertilizer was present in the modeled situation which was not so in the experiments.

Remarks: Also this group had no common language. The simulation of the effect of variations in temperature was impossible in the time span available. The yield simulated for a prolonged humid period are amazingly low, and presence of a programming error may be suspected.

4.3.4.- Group 4.-

Objectives: To simulate how a variable availability of nitrogen from the soil affects production of a grain maize crop with plenty of water and in two climates.

Action taken: SUCROS was adapted to simulate maize by choosing crop specific parameters and functions. Weather data for Maracay were introduced. An extra "organ" was defined: the hull plus stalk of the cob was distinguished from the grain in the cob. The effect of nitrogen shortage on crop growth was implemented as the course textbook indicates. The new organ was programmed to behave first like grains: importing nitrogen, and later to behave like vegetative organs: exporting nitrogen to the grain.

Results: The program was used to simulate growth in soils of which the available nitrogen ranged from extremely low (20 kg ha^{-1}) to optimal (240 kg ha^{-1}). This corresponds with a soil with a very low fertility, supplied with a dose of nitrogenous fertilizer ranging from 0 to 400 kg ha^{-1} at a recovery of nitrogen of 55%. A typical example is presented in Figure 3. No time was left to repeat the simulations for another climate, but the difference was expected to be low anyway. The effect of increasing the maximum rate of leaf photosynthesis from 45 to 50 kg $ha^{-1}h^{-1}$ turned out to increase yields proportionally in these situations.

Remarks: The simulation of cob stalk separate from the grain was a new and elegant feature introduced by this group. The results obtained are quite realistic.

4.3.5.- Group 5.-

Objectives: (a) To evaluate the effect of large fluctuations in temperature on photosynthesis, growth and transpiration of a potato crop in Temuco,, Chile, with ample fertilizer, (b) to evaluate the effect of drought on crop growth and water use.

Actions taken: Parameters and functions were specified for the potato crop, and weather and soil data were introduced. The effect of temperature was described in more detail by considering average daytime and average nighttime temperatures, and weighting their effects on the processes rather than weighting the temperatures. It was hypothesized that the dry matter distribution over the organs is affected by the size of the daily fluctuations in temperature: fluctuations of 10 to 20°C are optimal and stimulate tuber growth, while both larger and smaller differences decrease tuber growth. Similarly, a minimum temperature of 12 to 18°C is optimal, and both higher and lower values reduce tuber growth.

Figure 3

The total grain yield of a maize crop (as a percentage of the maximum simulated, heavy line) and the harvest index (thin line) are plotted as a function of the amount of nitrogen absorbed from the soil. The concentration of nitrogen in the grain (dotted line) is plotted as well. The grain yield in optimal conditions (L1) was 9134 kg ha^{-1}.

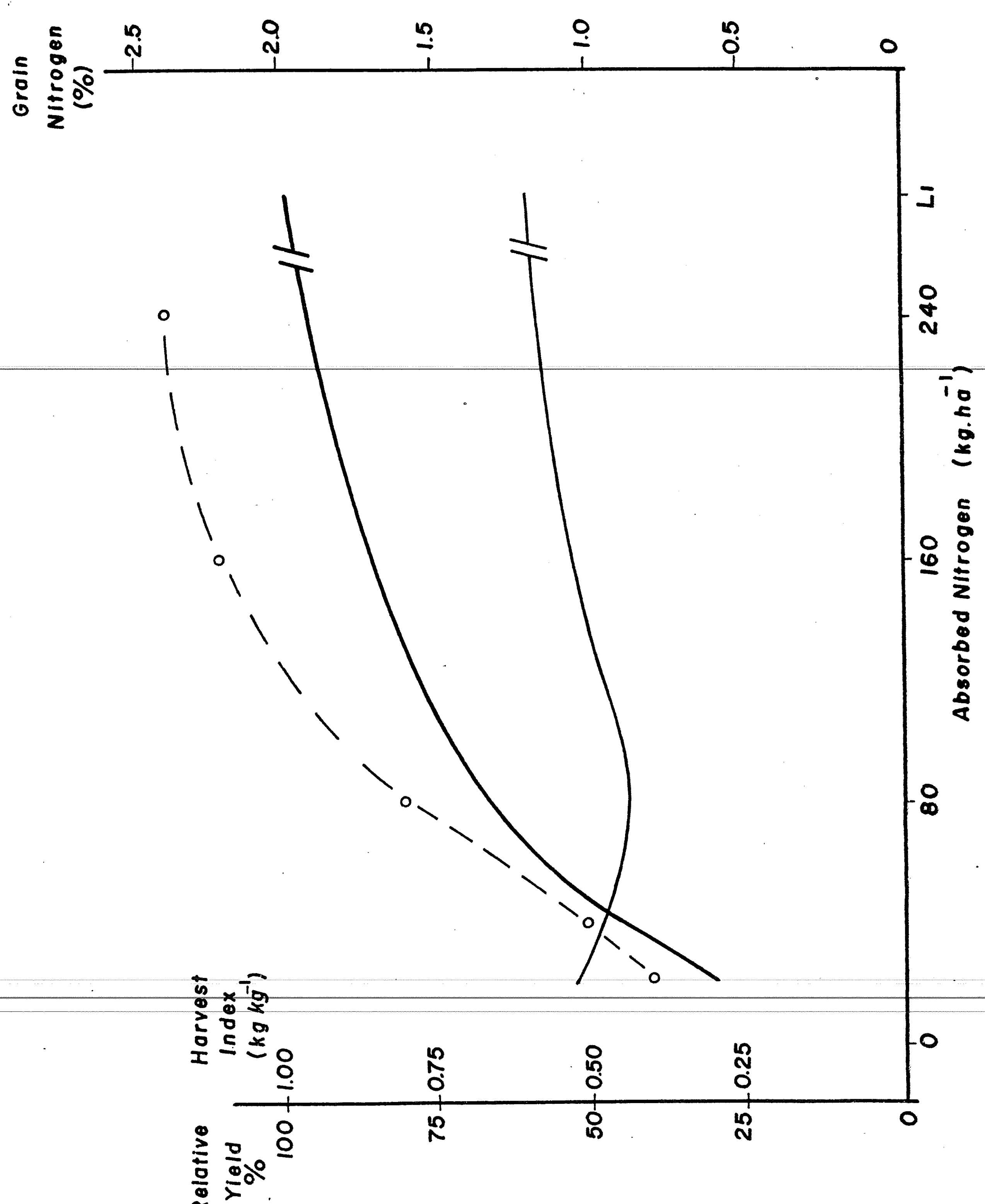


Fig. 3.

Results: Some results are presented in Table 2. A combination of a 15°C minimum and a 25°C maximum temperature provides the best temperature regime for potato production and yields 19.7 t ha^{-1} of tuber dry matter. The sensitivity of tuber production for the temperature regime is also shown in the table.

Remarks: This is a nice example of investigating the effect of a hypothesis on the effect of temperature on dry matter distribution.

4.3.6 Group 6.-

Objectives: To evaluate the implications for production of different hypotheses of regulation of dry matter distribution in a cassava crop in Central Venezuela with optimal water and fertility conditions.

Actions taken: The dry matter distribution functions were adapted for cassava and made a function of temperature: the higher the temperature the less dry matter is invested in the storage organ. The program was run for 365 days.

As results were not encouraging (too low yields), changes were made of parameters to find out which ones were most important for yield.

Results: The sensitivity analysis of model parameters yielded the following: increasing the specific leaf area turned out to lead to appreciably higher yields: increasing the weights of roots, stems and leaves shortly after planting had little effect. The effect of different planting dates was almost zero. A lower rate of maintenance respiration in the storage organs was found

Table 2.- Yields of a potato crop in Chile in different temperature regimes. Results are expressed as a fraction of the highest yield of 19.7 t ha^{-1} of dry matter (65.6 t ha^{-1} of fresh weight).

	maximum temperature					
	5	10	15	20	25	30
minimum temperature						
5	0.02	0.21	0.35	0.35	0.33	0.16
10		0.04	0.55	0.78	0.78	0.74
15			0.05	0.70	1.00	0.93
20				0.04	0.55	0.78
25					0.02	0.30
30						0.00

to be very important to increase yield, and the suggested value is indeed more realistic for cassava than the one used in SUCROS. Combinations were tested as well. The most optimistic combination of parameters yielded 28 t ha^{-1} of cassava, which was still some 25% below the expectation of some group members, although the simulated leaf area index (5-6) was already higher than what is optimal for cassava (3-4).

Remarks: Lack of Maracay cassava field data for comparison with simulated data was a particular handicap.

4.3.7.- Group 7.-

Objectives: (a) To evaluate the effect of variation in temperature on photosynthesis, transpiration and growth of a tomato crop under California weather conditions and ample fertilizer, (b) compute the water requirement of such a crop.

Actions taken: A set of experimental data on growth of a field crop of tomato cultivar UC82 was present and quite helpful. The concept of a development stage of the crop in SUCROS was redefined as to be proportional to the number of heat units received (above 6°C). The observed dry matter distribution pattern was introduced. The conversion factor for growth processes was replaced by a slightly lower value, computed from the known atomic composition of the biomass. The root system of the tomato was thought to be extremely light, so that the root weight-root depth relation in the soil water section was adapted.

Results: A sensitivity analysis was performed on the influence of the maximum rate of leaf photosynthesis, as some controversy of its value persists. The tomato yield turned out to increase by 25% when the maximum photosynthesis rate was increased by 15%. This result is typical for crops that do not cover the soil fully and where accelerated early growth leads to a higher leaf area.

Several runs were made with the carbon balance -water balance program to find the response curve of crop yield to water supply. Irrigation was programmed to occur in preset amounts and at regular intervals. The result, given in Fig.4, shows that a total supply of about 700 mm is close to optimal.

Remarks: Though probably not yet accurate, this program shows a realistic behaviour.

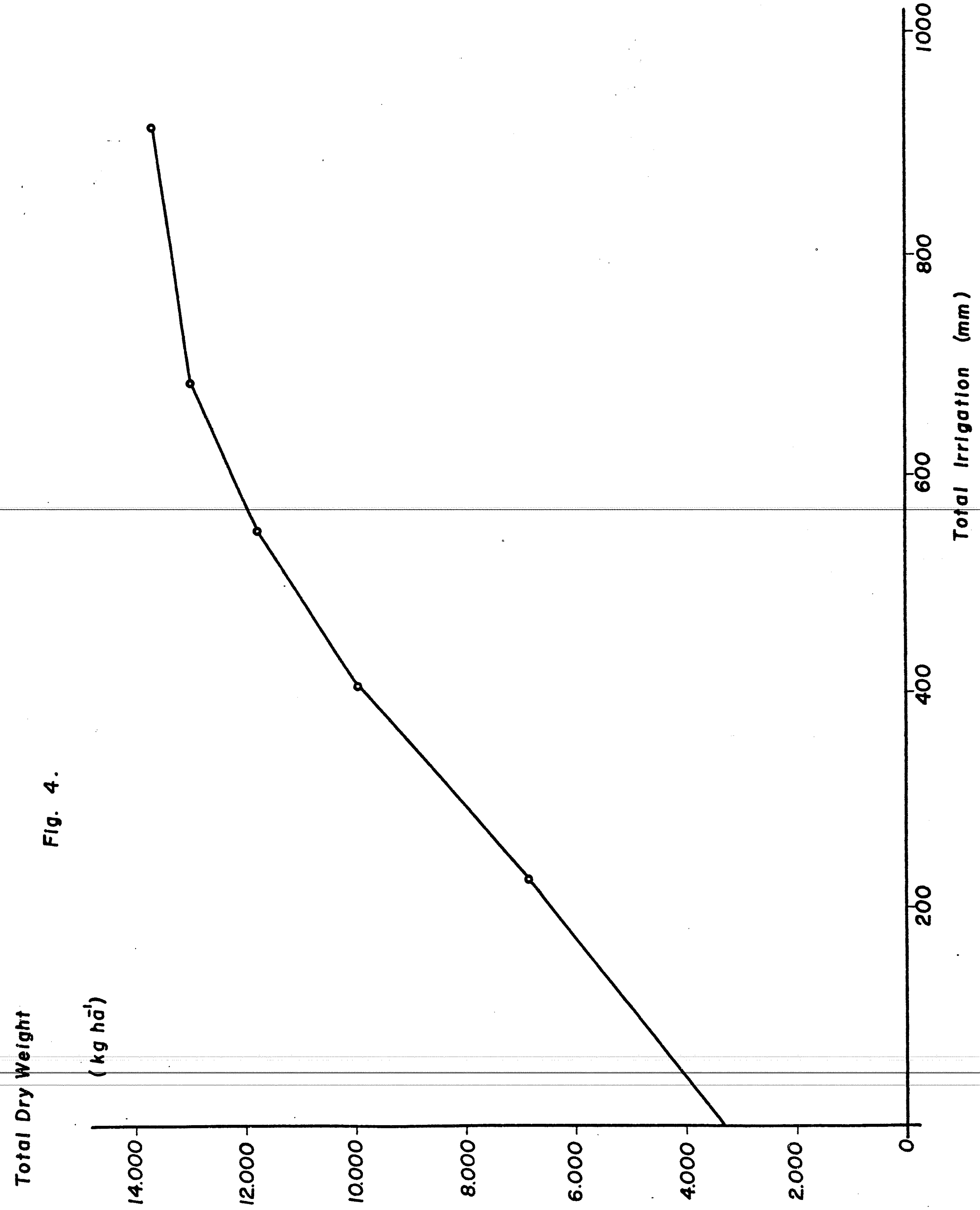
4.3.8.- Group 8.-

Objectives: (a) To study the carbon balance and dry matter partitioning in the cassava crop in optimal conditions, (b) study the water balance and adapt it to conditions for cassava in Maracay, and (c) to combine both programs and to devise some recommendations for crop management and/or breeding.

Actions taken: An alternative hypothesis was formulated about regulation of dry matter distribution: leaf and stem growth have first priority in consumption of assimilates, and the remainder goes to the storage organ. Leaf and stem production are proportional to the rate of formation of branches, leaves and of leaf size, any of which are functions of time. Leaves are subdivided into 30 age classes, and die after a life span of 100 days. This hypothesis was supported by many field data. The water balance

Figure 4

The response of the total dry weight of the tomato crop to the amount of irrigation water applied.



was adapted to Maracay conditions and cassava crop. It yielded results only late due to technical problems with DARE-P.

Results: The carbon balance, after cleaning up some errors of programming and parameter calculating, showed a more or less reasonable behaviour, so that combining the model with the water balance was considered useful. However, the combined program appeared too large for DARE-P. Reducing its size by going to 15 instead of 30 leaf age classes solved this problem, but a new program error came up which could not be resolved during the course.

Remarks: Afterwards, the last error turned out to be a minor matter related to formulation of the new dry matter distribution hypothesis, and was cured. The program still required some work to improve its behaviour, but it seems to be of use for guiding future research, such as integration of physiological knowledge of this crop, and comparing of implications of alternative hypotheses.

5. CONCLUSIONS AND RECOMMENDATIONS

This course has been successful. Strong sides were the coherence of the lectures and integration of theory and practice. A weak side was the excess of information and exercises provided during the intensive course of 2 weeks. This is partly due to the subject, partly to the fact that participants and lecturers do not really like courses much longer than 2 weeks. A solution, suggested by participants, seems to be to have a refresher and follow up course about 2 years after the first one.

The topic of modeling of crop growth appeared of considerable interest to the participants of third world countries and to many more who applied for the course, but could not be invited. This was confirmed in the course evaluation: modeling provides a better insight into processes related to plant growth and crop production than other methods. To a limited extent the course provided participants with the knowledge to apply modeling techniques after the course to their own problems. The degree to which they can make use of this in practice will depend upon availability of a suitable computer and simulation language (both of which are not yet abundant) and the degree to which they are able to co-operate with colleagues on simulation topics, which are almost always of a multidisciplinary nature. If a follow up course is considered, it is useful to inquire after uses made of acquired knowledge by first time participants. Previous experience in modeling or computer use appeared to be a limited, and temporary advantage to some and even a disadvantage to others.

The distance between Wageningen and Caracas is not a major barrier for co-operation in order to organize and execute specific courses. In fact, it seems an excellent opportunity for courses prepared outside IDEA on topics of interest to third world countries to be given for all parties involved. This applies particularly, but not exclusively, to courses organized by the Foundation for Post Graduate Courses of the Agricultural University in Wageningen.

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APPENDIX 2- REFERENCES

R E F E R E N C E S

Bras R. and J. Córdova. "Intraseasonal Water Allocation in Deficit Irrigation". Water Resources Research, 17 (2), 1982.

Callaos, N. "Simulation of Living Systems". IDEA, Caracas, 1982.

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Cock, J.N. "The Role of Crop Physiology in Increased Production in The Tropics". IDEA, Caracas, 1982.

Córdova,J. and R. Bras. "Physically Based Probabilistic Models of Infiltration, Soil Moisture and Actual Evapotranspiration". Water Resources Research, 17 (2), 1981.

Penning de Vries, F.W.T.and H.H. Van Laar. Simulation of plant growth and crop production. Simulation Monographs. PUDOC, Wageningen, 1982. 308 p.

Van Keulen, H. and H.D.J. Van Heemst. "Crop response to the supply of macronutrients". Agricultural Research Reports, 916, PUDOC, Wageningen, 1982, 46 p.

APPENDIX 3.- COURSE PROGRAM

MODELING OF CROP PRODUCTION

P R O G R A M

I. SYSTEMS, ANALYSIS AND METHODS

Monday, November 1st

1. Simulation of living systems (N. Callaos)
2. Systems analysis of crop production (F. Penning de Vries)
3. Introduction to dynamic simulation: Calculus (R. Rabbinge)

Tuesday, November 2nd

1. Introduction to dynamic simulation: C.S.M.P. (H. Van Laar)
2. A simple crop growth model: SUCROS (R. Rabbinge)
3. Phases of model development (N. Callaos)

II. POTENTIAL PRODUCTION

Wednesday, November 3rd

1. Using the simple crop growth model (F. Penning de Vries)
2. Photosynthesis and transpiration (R. Rabbinge)
3. Hierarchy, and coordination of submodels (L. Stroosnyder)

Thursday, November 4th

1. Respiration and vegetative growth (L.J.M. Basstanie)

2. Growth of reproductive organs (F. Penning de Vries)

3. Simulation of crop growth (R. Rabbinge)

III WATER AND PLANT NUTRIENTS

Friday, November 5th.

1. Efficiency of water use (L. Stroosnyder)

2. The soil water balance (J.R. Córdova)

3. Crop production and nitrogen availability (H.Van Heemst)

Monday, November 8th

1. The reliability of input data (N. Callaos)

2. Advanced simulation methods. (R. Rabbinge)

3. Hydrolic soil water models (J.R. Córdova)

Tuesday, November 9th

1. Stochastic models (J.R. Córdova)

2. Soil fertility processes (L. Stroosnyder)

3. Simulation of nitrogen stress (H. Van Heemst)

Wednesday, November 10th

1. Pests and diseases (Rabbinge)

2. The Centre for World Food Studies (H. Van Heemst)

3. Use of models (F. Penning de Vries)

IV CASE STUDIES

Thursday, November 11th

Case studies

Friday, November 12th

Case studies

EVENING AND SOCIAL PROGRAM

Monday, November 1st.	Cocktail.
Tuesday, November 2nd.	Films about the Netherlands.
Thursday, November 4th.	Modeling Cassava Crop (J.Cock)
Saturday, November 6th.	Excursion
Sunday, November 7th.	Free
Tuesday, November 9th.	On Evaluation of models (J. Cock)
Wednesday, November 11th.	Crop Engineering: Comprehensive Model of Agricultural Production (A. Norero)
Friday, November 12th.	Afternoon: Evaluation of the course Evening: Folklore

APPENDIX 4.- DIFFERENCES BETWEEN CSMP AND DARE-P

This note was prepared for this course. It indicates differences between CSMP and DARE-P and is to be used with CSMP as a point of reference (I.B.M. Continuous System Modeling Program, Program Reference Manual, SH19-7001-3. Technical Public Dept., White Plains, U.S.A. 206 pp.).

DARE-P is a simpler simulation language than CSMP is, but most exercises of the textbook "Simulation of Plant Growth and Crop Production" can be executed with it. DARE-P runs on PDP-11 computers.

1. The structure of a simulation program in DARE-P is more rigid than that of CSMP program:

All equations of a model are to be inserted in the DYNAMIC block, and they may be in the order that the user desires. A block for calculations initialize the program (Initial) does not exist. The dynamic block is preceeded by a line with the label $D1. Reruns, if any, are to be initiated in the next block (proceeded by $L). Tabular data are entered in the next block: use a line with $T before each new table. Self defined functions, if any, are specified in a Fortran block preceeded by $F. In the next block, on one line only, one specifies the integration routine to be used ($M2 calls for METHOD TRAPZ, $M4 calls for METHOD RKSFX and $M6 calls for METHOD RECT. These blocks are always in this order, but $L, $F and $T may be absent.

The total of these blocks is terminated with END. The initial values of state variables and the values of parameters and constants are then given in a free format. Also the values of the timer variables are specified in this data block, which is closed with END. Finally, there is a part to specify the program output; this closes also with END.

2.Equations are written in the columns 7-72, the labels $D1 etc. start in column 2, END in column 1. Continuation of an equation into the next line is achieved FORTRAN style by inserting a character (non ϕ) in column 6. No continuation is allowed in the data block. Comments start with C or * in column 1; only C can be used for this purpose in $F. The data of the tables may be written in any column between 2 and 72, but only one pair of data per line (or: one data set per line in two dimensional tables), which may lead to fairly long tables. Check whether the number of pairs of data equals that indicated as the second argument of the call of a table (see also item 4), because DARE-P does not do this.

3.Names of Variables.-

- Use 5 characters at most (6 is admitted in a number of cases, but uniformity is easier).

- The first letter of the (real) variables starts with A to H or with O to Z, the others are always integers.

- Z should not be used as the last letter of names.

- "reserved names". Use never: variables named S, IS and AS; only to the right of the = sign should timer variables be used. The DARE-P counterpart of KEEP has not yet been traced.

4.Available Functions.

- The INTGRL is written as: "state variable name dot = rate": the initial value is not shown in this equation but specified in the data block as "state variable = initial value". See Example 1 at the end of this note.

- The MACRO feature of CSMP is unavailable.

- Most other CSMP functions are available from the DARE-P library or are made of by us. The latter ones are defined in the Fortran block $F.

- The AFGEN function is available but has a different form: the name of the function is mentioned instead of the name AFGEN, and between parentheses the independent variable. Separately in the $T block the name of the function is given followed by the number of pair of data in the table. See Example 2.

- The PROCEDURE is present; specify all names of input and output variables (and not only those required for sorting as in CSMP). PROCEDURES'S do not have own names. See Example 3.

- The NOSORT option does not exist. The block $F is always "procedural".

5. Output.

- Lists of variables are obtained by: LIST, A,B,etc. This generates tabular output of up to 7 variables (A,B, etc) with the variable time (T). More printed variables can be obtained by repeating "LIST, etc." with other names.

When using reruns, for each run LIST has to be specified, see Item 7.

- Graphical output can have two forms: a graph with time as the independent variable or a graph with another variable of the program as independent variable.

The first is obtained by: PLOT, A, B, etc. which plots up to 7 variables in one graph; the second form is obtained by PLOTXY, A,B, etc, also with a maximum of 7 dependent variables in one graph, A is the independent variable. All graphs are automatically scaled.

Plot and print interval are not given as such, but indirectly through the number of points to be printed or plotted: NPOINT. Hence: NPOINT = FINTIM/PRDEL+1. Print and plot interval are equal.

6. Timer variables.

TIME in DARE-P is called T, FINTIM (FINISH TIME) is called TMAX, DELT (TIMESTEP OF INTEGRATION) is called DT. T always initiated at 0.

7. Reruns.

The block $L should start with CALL SAVE, CALL RUN, CALL RESET (at separate lines). New initial values of state variables and/or parameters can be specified. New data for existing tables cannot be entered in a rerun; the easiest way to get around this problem may be to give all tables for reruns in the main program, and to choose the appropiate table by means of an INSW.

TMAX must be specified each run again. Output can be changed in reruns. Please note that each run must have its own numbered LIST for output; see Example 4.

8. Execution of DARE-P programs.

Programs in DARE-P are executed in three phases. Each phase produces its own output in which messages of errors can be included.

The subprogram DPRE makes from the source file with the original program two sorted and numbered FORTRAN files (DARE.FTN, DIFFEQ.FTN).

These files are compiled and "task built". The created sub-routines are linked with library subroutines. The source file, checked on DARE-P language errors, is written into a file named FORΦΦ6.DAT;1. The sorted and numbered listing of the program is named DIFFEQ.LST; this file may include FORTRAN messages (warnings or fatal errors). If DPRE encountered no fatal errors, the appropiate files are submitted to the subprogram DARE.

The subprogram DARE carries out the computations. It creates output in a file named FORΦΦ6. DAT;2. It contains the timer variables and the output of FORTRAN statements included in the source program. The subprogram DOUT prepares the output generated by DARE for proper printing and plotting, and puts its results in the file named FORΦΦ6.DAT;3.

The three FORΦΦ6.DAT files are automatically copied and combined into a new file; OUTPUT.DAT. This file can be send to the line printer.

9. Running a program.

Running the sequence of the three subprograms is induced by calling the control file DARE. CMD by typing "DARE". The terminal will ask then for the name of the source file (e.g. EXERCE5.CSM). Most warnings and errors will be send to the FORΦΦ6.DAT files for inspection later. However, during compilation of the DIFFEQ file, messages may appear on the terminal. Recall their line numbers and check afterwards these lines in DIFFEQ.LST where the error is explained (e.g.; too many left parentheses, or $LD instead for $D1, or starting in the wrong column). In case of fatal errors, the execution of the

DARE file should be aborted. This should be done by pushing the CTRL and C-key at the same moment (↑C). The monitor responds with ' > ' and you type ACT. All the messages that appear can be terminated by typing e.g. ABO TKB until just MCR...and...MCR are left over. Now change your source-file and you can run the program again.

```
*       EXAMPLE 1

 $D1
        WSH.= GSH
        WRT.-GRT
        TWT=WSH+WRT
        GRT=0.3*GTW
        GSH=0.7*GTW
        GTW=(GPHOT-RMAINT)*CVF
        RMAINT=(WSH+WRT)*0.015
        GPHOT=GPHST*(1.-EXP(-0.7*RLAI))
        RLAI=AMIN1(WSH/500.,5.)

 $M6
END

        WSH=50.,WRT=50.,CVF=0.7, GPHST=400.
        TMAX=100.,DT=1.,NPOINT=21

END
        LIST, TWT, WSH, WRT, GTW
        PLOT, TWT

END

*       EXAMPLE 2

 $D1

        WSH. =GSH
        WRT. =GRT
        TWT=WSH+WRT
        GRT=0.3*GTW
        GSH=0.7*GTW
        GTW=(GPHOT-RMAINT)*CVF
        GPHOT=GPHST* (1.-EXP (0.7*RLAI))
        RLAI=AMIN1(WSH/500.,5.)
        GPHST=GPHSTB (DAY)
        DAY=STDAY+T

 $T

        GPHSTB,4
        60., 300.
        100., 400.
        150., 450.
        210., 500.

 $M6
END
        WSH=50., WRT=50., CVF=0.7, STDAY=60.
        TMAX=150., DT=1., NPOINT=31

END
        LIST, TWT, WSH, WRT, GTW, GPHST

END
```

```
*       EXAMPLE 3

 $D1

        PROCED  XS=N1,T
        XS=0
        IF (T.LT.N1) GOTO 10
        I=N1

 11     XS=XS+I
        I=I+1
        IF (I.GT.T)  GOTO  10
        GOTO 11
 10     CONTINUE
        ENDPRO

END

        TMAX=9.9
        N1=0, NPOINT=4

END
        LIST,  XS

END

*       EXAMPLE 4

 $D1

        WSH.=GSH
        WRT.=GRT
        TWT=WSH+WRT
        GRT=0.3*GTW
        GSH=0.7*GTW
        GTW=(GPHOT-RMAINT)*CVF
        RMAINT=(WSH+WRT)*0.015
        GPHOT=GPHST*(1.-EXP(-0.7*RLAI))
        RLAI=AMIN1. (WSH/500.,5.)

 $L

        CALL SAVE
        CALL RUN
        CALL RESET
        GPHST=400.
        CALL SAVE
        CALL RUN
        CALL RESET
        GPHST=500.
        CALL SAVE
        CALL RUN

 $M6
END

        WSH=50.,WRT=50.,CVF=0.7,GPHST=300.
        TMAX=100.,DT=1., NPOINT=21
```

```
END

        LIST (1) TWT, WSH, WRT
        LIST (2) TWT, WSH, WRT
        LIST (3) TWT, WSH, WRT
        PLOTXY (3) WSH, WRT

END
```