

ANALYSIS OF PLANT GROWTH SIMULATION MODELS

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ABSTRACT

Plant process models typically require many empirical parameters for which experiments obtain the initial values. The relative accuracy of each of these parameters will have varying degrees of importance in terms of their effect on yield as predicted by the simulation model.

Various methods of examining the "sensitivity" of the response to changes in these parameter values have established an improved correspondence between model predictions and observed yields. This report presents a specific systematic statistical procedure (along with computer programs) by which plant process modelers may determine which parameters require a high degree of accuracy.

The primary purpose of the report is to document the computer programs used in the analysis of plant process models so that a modeler may adapt the techniques. There is an introductory section on the choice of experimental designs. A program description section illustrates adaptations to a prototype model (SOYGRO) for running the designs. Sample programs illustrate how the programs operate.

INTRODUCTION

Computational models that simulate plant growth and development require a large number of parameters which may have a significant effect on a response of interest. For example, plant yields per acre, grain weight per ear, and number of seeds are strongly affected by physical parameters such as the concentration of CO₂. Extensive series of experiments to determine appropriate values of parameters may be necessary. Many other physical parameters (for example, the amount of glucose required to produce one gram of stem or shell) may have only a minimal effect on the final response of interest, yet accurate estimates of those parameters could require costly experimentation under varying field parameters. For example, when a variation of 25 per cent or more in a given parameter produces less than one per cent difference in yield, the original estimate is acceptable in the computational model. This determination can eliminate the need for costly experiments to obtain more precise values for such parameters.

Theoretically determined quantities often require correction by empirical factors. An example taken from SOYGRO¹ is a "factor to reduce the gross photosynthetic equation so that simulated growth corresponds to field samples". Before using computational models that simulate plant growth reliably for the estimation of yield, the user should know the effect of such

empirical parameters.

The Estimates Research Section (in the National Agricultural Statistics Service's Statistical Research and Applications Division) of the U.S. Department of Agriculture initiated a Cooperative Research Agreement with the University of Georgia, Department of Statistics in June, 1985, to develop tools for systematic sensitivity analyses of plant process simulation models for personal computers [IBM PC-XT/AT]. The soybean plant process model known as SOYGRO was the prototype for the study for the following reasons:

- 1) Preparation of an IBM PC adaptation (under MICRO SOFT FORTRAN) of their program was complete;
- 2) Thorough and complete documentation was available; and,
- 3) The program structure made variation of parameters simple, because all "normal" parameter values were in data files read at the beginning of each simulation run².

Rebuilding SOYGRO for systematic simulation runs required major modifications in only two units (the MAIN program and the final reporting program HVSTRP), the addition of one subroutine (PARCON), and only minor modifications in the other programs.

The Statistical methodology section describes the statistical methods employed in the sensitivity analysis programs. Several "Sample Sessions" explain the use of the modified simulation program for the implementation of fractional factorial experiments under a Balanced Incomplete Block Design.

STATISTICAL METHODOLOGY

The Youden Square (Balanced Incomplete Block Design)

Under the assumption of non-significant contributions for three-way and higher interactions, there are two methods to obtain valid estimates of all main effect and two-way interaction contrasts. One method would be to study each pair of parameters at a time. This would require a manageable number of 840 runs for 21 factors. The other method would be to take a 1/64 fraction of a 2²¹ design to guarantee unaliased main effects and two-way interactions.

Another possibility arises from the study of five factors. The study of five factors requires only 16 runs to obtain unaliased main effect and pairwise interaction estimates. This would make possible studying "five-at-a-time" while keeping the other 16 neutral and performing the 16 runs. These five parameters represent a "Block." However, each pair of factors or parameters must occur at least once in such a block of five.

Such a design is possible with a "Balanced Incomplete Block" (BIB) design. A desirable (though not absolutely necessary) feature of BIB designs for fractional factorial experiments is that the role of factors and blocks be interchangeable so that the design will be its own dual. The Youden Square (see, for example, Cochran and Cox [1957]) is such a design. The most famous Youden Square is for a block size of three with seven treatments as follows:

1	2	5
3	4	5
1	3	6
2	4	6
1	4	7
2	3	7
5	6	7

Each pair of factors occurs exactly in one block. Block numbers are interchangeable to produce the same design. The Youden-square of block size five has 21 treatments as follows:

1	2	3	4	17
5	6	7	8	17
9	10	11	12	17
13	14	15	16	17
1	5	9	13	18
2	6	10	14	18
3	7	11	15	18
4	8	12	16	18
1	6	11	16	19
2	5	12	15	19
3	8	9	14	19
4	7	10	13	19
1	7	12	14	20
2	8	11	13	20
3	5	10	16	20
4	6	9	15	20
1	8	10	15	21
2	7	9	16	21
3	6	12	13	21
4	5	11	14	21
17	18	19	20	21

This design defines the compromise solution for analyzing the model parameters. The field plan defines how "five-at-a-time" subsets of 21 variables vary while the remaining 16 parameters in each block remain neutral. Assuming that triple and higher interactions are negligible, each block needs 16 settings. Each block of the BIB design consists of 16 replications of a fractional factorial design, that is, each block is a 1/2 replication of a fractional factorial with an even number of high levels. Valid main effect and pairwise interaction effect estimates of the 21 parameters are available after a total of $21 \times 16 = 336$ runs of the simulation model.

The reason for using examples with 21 parameters should be clear now. Under the given assumptions, the BIB design with 21 factors offers probably the most dramatic reduction in the number of experiments of other possible designs.

Fortunately, selecting overlapping subsets of 21 from among the 45 parameters which the modelers chose as most significant was not difficult for the SOYGRO model. Most parameters had so little effect on the response that even after major modification of the normal settings, no design required more than 21 factors in the

same run.

Analysis of 21 Parameters: Fractional Factorial and BIB Designs

This section describes computer programs for the IBM PC/XT or AT for the Youden Square design described above. See the Appendix for the flow-chart.

The first step is to prepare the input data file named YODEN.DAT. YODEN.DAT has the following simple structure:

```
10 1 10 2 11 1 11 2 11 3 11 4 11 5 11 6 12 1
13 1 13 2
13 3 13 4 14 1 14 2 14 3 14 4 30 1 30 2 30 3
31 3.
```

This layout specifies that the 21 parameters to be modified (in the datafile SOY50.DAT) are those in line 10, field 1; line 10, field 2; line 11, field 1; ... line 31, field 3 with a (10(I3,I2)) format. From these data, the program YODEN.EXE prepares a control file called INFACF on the same disk drive. INFACF has the following form:

10	1	10	2	11	1	11	2	14	4
11	3	11	4	11	5	11	6	14	4
12	1	13	1	13	2	13	3	14	4
13	4	14	1	14	2	14	3	14	4
10	1	11	3	12	1	13	4	30	1
10	2	11	4	13	1	14	1	30	1
11	1	11	5	13	2	14	2	30	1
11	2	11	6	13	3	14	3	30	1
10	1	11	4	13	2	14	3	30	2
10	2	11	3	13	3	14	2	30	2
11	1	11	6	12	1	14	1	30	2
11	2	11	5	13	1	13	4	30	2
10	1	11	5	13	3	14	1	30	3
10	2	11	6	13	2	13	4	30	3
11	1	11	3	13	1	14	3	30	3
11	2	11	4	12	1	14	2	30	3
10	1	11	6	13	1	14	2	31	3
10	2	11	5	12	1	14	3	31	3
11	1	11	4	13	3	13	4	31	3
11	2	11	3	13	2	14	1	31	3
14	4	30	1	30	2	30	3	31	3

INFACF has 21 lines which describe the five parameters for each line that form a block as determined by the Youden Square (21) design. This is the only input file required by SENSOY.EXE for the 336 simulation runs.

The second step is to execute the modified SOYGRO program (SENSOY.EXE). At the beginning of this run, all weather and field data files must be in the default drive. Also, since several of the SOYGRO routines refer to drive B, the statement "ASSIGN B=C" must be executed. Major modifications were necessary in the MAIN program and the final reporting program HVSTRP only.

A parameter conversion program named PARCON has been added. As mentioned above, the control file (INFACF), a datafile (SOY50.DAT) and a descriptor file (SOY50.DES) control the program flow (see Appendix). After supplying the input parameters from the weather and field data, the user will give a name to the output file, for example, A:BIB230.IN. The typical

output file appears as follows³:

10	1	10	2	11	1	11	2	30	1
-1	-1	-1	-1	-1				37.744	
1	-1	-1	-1	1				43.538	
-1	1	-1	-1	1				46.970	
1	1	-1	-1	-1				32.815	
-1	-1	1	-1	1				48.618	
1	-1	1	-1	-1				33.901	
-1	1	1	-1	-1				36.130	
1	1	1	-1	1				42.095	
-1	-1	-1	1	1				48.607	
1	-1	-1	1	-1				33.928	
-1	1	-1	1	-1				36.163	
1	1	-1	1	1				42.097	
-1	-1	1	1	-1				37.331	
1	-1	1	1	1				43.543	
-1	1	1	1	1				46.739	
1	1	1	1	-1				32.447	
...
30	1	30	2	30	3	31	3	31	5
-1	-1	-1	-1	-1				34.705	
1	-1	-1	-1	1				43.775	
-1	1	-1	-1	1				37.576	
1	1	-1	-1	-1				48.803	
-1	-1	1	-1	1				35.237	
1	-1	1	-1	-1				43.623	
-1	1	1	-1	-1				37.909	
1	1	1	-1	1				48.219	
-1	-1	-1	1	1				35.020	
1	-1	-1	1	-1				43.775	
-1	1	-1	1	-1				37.576	
1	1	-1	1	1				46.328	
-1	-1	1	1	-1				35.237	
1	-1	1	1	1				44.226	
-1	1	1	1	1				39.117	
1	1	1	1	-1				48.219	

The third step is to execute program BIB.EXE. This program uses the second step of output to produce summary and detailed analysis of all main effects and first-order interactions. The following sample session illustrates the procedure.

**Sample Session 1
Preparation of INFACF file**

The text editor EDLIN can prepare a file called A:YOUDEN.DAT (required name) as follows:

```
edlin a:youden.dat

New file
*i
  1:*  3 3  3 5  3 7  3 9 10 1
      10 2 11 1 11 4 12 1 13 1
  2:* 13 2 14 1 14 2 15 1 15 2
      15 3 25 1 25 2 27 1 27 2
      28 3
  3:* ^C
*e
```

The file YOUDEN.EXE must be on a diskette (A-Drive), with the files YOUDEN.DAT and INFACF.

```
a:youden
Stop Program terminated
type a:infact
  3 3 3  5 3  7 3  9 25  1
10 1 10 2 11 1 11 4 25  1
12 1 13 1 13 2 14 1 25  1
14 2 15 1 15 2 15 3 25  1
  3 3 10 1 12 1 14 2 25  2
  3 5 10 2 13 1 15 1 25  2
  3 7 11 1 13 2 15 2 25  2
  3 9 11 4 14 1 15 3 25  2
  3 3 10 2 13 2 15 3 27  1
  3 5 10 1 14 1 15 2 27  1
  3 7 11 4 12 1 15 1 27  1
  3 9 11 1 13 1 14 2 27  1
  3 3 11 1 14 1 15 1 27  2
  3 5 11 4 13 2 14 2 27  2
  3 7 10 1 13 1 15 3 27  2
  3 9 10 2 12 1 15 2 27  2
  3 3 11 4 13 1 15 2 28  3
  3 5 11 1 12 1 15 3 28  3
  3 7 10 2 14 1 14 2 28  3
  3 9 10 1 13 2 15 1 28  3
25 1 25 2 27 1 27 2 28  3
```

**Sample Session 2
SENSOY Program Run for
one Weather-Field Scenario
Example Field
Quincy, Florida**

The default drive should now be the directory which contains all the weather and field data files. Since some of the SOYGRO subprograms point to drive B:, an ASSIGN B=C is necessary to use the hard disk as the default drive for these files. All files required by the simulation program are in the <DIR> c:\SOYGRO. The SENSOY.EXE program is in RAMDISK H:. The diskette containing the INFACF file from the previous session is still in Drive A:.

```
assign b=c
cd \rolf\exe (contains SENSOY.EXE)
copy sensoy.exe H:(RAMDISK is drive H:)
cd \soygro The SOYGRO directory
has all weather, field data
H:SENSOY
Execution Begins

Enter 0 for yield on disk file (default)
1 for detail disk files, (-1) for debug
0
Enter block number and rep number(1 to 16)
(1 0) if this is the first (neutral) run
1 0
State the full file name for output
for wexample: (a:teem)
a:bib580.in
Enter 3 numbers for Weather data, field
comparison and irrigation schedule
(eg. 2 3 0 for FL 79)
5 8 0

Weather,Field,Irrigation = 5 8 0

Enter photosynthetic factor (e.g. 0.84)
0.95
Photosynthetic factor now at .950
```

ALL FACTORS NEUTRAL

READING WEATHER DATA - PLEASE WAIT...
 SAMPLE DATA FILE =
 QUINCY, FLORIDA IRRIGATED FIELD, 1979

PHOTOSYNTHETIC FACTOR = .95

SIMULATION HAS BEGUN....PLEASE WAIT.
 DON'T TOUCH THE TERMINAL UNTIL PROMPTED.

OCCURRENCE OF PHENOLOGICAL EVENTS

EVENT	DAYS FROM PLANTING	CALENDAR DATE
EMERGE	8	JUL 3
V1	14	JUL 9
JUV.PH.	18	JUL 13
R0	33	JUL 28
R1	44	AUG 8
PODSTART	61	AUG 25
R4	61	AUG 25
ENDLEAF	61	AUG 25
ENDSET	84	SEP 17
R7	119	OCT 22
R8	150	NOV 22

TOTAL:
 NUMBER OF IRRIGATION APPLICATIONS: 0
 AMOUNT OF IRRIGATION: .000 INCHES
 COST OF IRRIGATION: \$.00
 CROP YIELD SUMMARY

SOYBEAN YIELD: 45.436 HUSHELS
 GROSS RETURN: \$ 318.05
 PRODUCTION COSTS: \$ 128.69
 SCOUTING COSTS: \$.00
 TOTAL COSTS: \$ 128.69
 NET PROFIT: \$ 189.36

Completed simulation
 block 1 Replication 0
 3 3 1
 3 5 1
 3 7 1
 3 9 1
 25 1 1

SIMULATION HAS BEGUN....PLEASE WAIT.
 DON'T TOUCH THE TERMINAL UNTIL PROMPTED.

CROP YIELD SUMMARY

SOYBEAN YIELD: 43.040 HUSHELS
 GROSS RETURN: \$ 301.28
 PRODUCTION COSTS: \$ 128.69
 SCOUTING COSTS: \$.00
 TOTAL COSTS: \$ 128.69
 NET PROFIT: \$ 172.58

Completed simulation
 block 1 Replication 3
 3 3 2
 3 5 2

3 7 1
 3 9 1
 25 1 1

SIMULATION HAS BEGUN....PLEASE WAIT.
 DON'T TOUCH THE TERMINAL UNTIL PROMPTED.

OCCURRENCE OF PHENOLOGICAL EVENTS

EVENT	DAYS FROM PLANTING	CALENDAR DATE
EMERGE	8	JUL 3
V1	14	JUL 9
JUV.PH.	18	JUL 13
R0	33	JUL 28
R1	44	AUG 8
PODSTART	61	AUG 25
R4	61	AUG 25
ENDLEAF	61	AUG 25
ENDSET	84	SEP 17
R7	119	OCT 22
R8	150	NOV 22

CROP YIELD SUMMARY

SOYBEAN YIELD: 40.740 HUSHELS
 GROSS RETURN: \$ 285.18
 PRODUCTION COSTS: \$ 128.69
 SCOUTING COSTS: \$.00
 TOTAL COSTS: \$ 128.69
 NET PROFIT: \$ 156.48
 Completed simulation
 block 1 Replication 4

After completion of the 336 runs, the output file named bib580.in as above looks as follows:

3	3	3	5	3	7	3	9	25	1
-1	-1	-1	-1	-1					47.595
1	-1	-1	-1	1					46.538
-1	1	-1	-1	1					43.040
1	1	-1	-1	-1					40.740
-1	-1	1	-1	1					47.595
1	-1	1	-1	-1					46.538
-1	1	1	-1	-1					43.040
1	1	1	-1	1					40.740
-1	-1	-1	1	1					47.595
1	-1	-1	1	-1					46.538
-1	1	-1	1	-1					43.040
1	1	-1	1	1					40.740
-1	-1	1	1	1					47.595
1	-1	1	1	1					46.538
-1	1	1	1	1					43.040
1	1	1	1	-1					40.740
25	1	25	2	27	1	27	2	28	3
-1	-1	-1	-1	-1					46.177
1	-1	-1	-1	1					45.512
-1	1	-1	-1	1					45.512
1	1	-1	-1	-1					46.177
-1	-1	1	-1	1					45.512
1	-1	1	-1	-1					46.177
-1	1	1	-1	-1					46.177
1	1	1	-1	1					45.512
-1	-1	-1	1	1					44.996
1	-1	-1	1	-1					45.598
-1	1	-1	1	-1					45.598
1	1	-1	1	1					44.996
-1	-1	1	1	-1					45.598

1	-1	1	1	1	44.996
-1	1	1	1	1	44.996
1	1	1	1	-1	45.598

The following pages present Sample Session 3 in which the BIB.EXE program produces estimates for all 21 main effects and all 210 interactions in the "summary" file by processing the output of the SENSOY run. The *.BLK file has some of the detailed steps of the BIB analysis for each of the 21 blocks.

Sample Session 3
Analysis of the BIB
- Fractional Factorial Design

```

bib
  Assume <DIR> contains the file BIB.EXE.
  State fully qualified name of input file
  a:bib580.in
  State the name of the summary output file
  a:bib580.sum
  State the name of the block output file
  a:bib580.blk
  HOW MANY BLOCKS ARE THERE (21 or 30) ?
  21
  BIB analysis completed
  
```

Excerpt of Printout of a:bib580.sum (Estimates):

```

1 THIS IS FILE h:bib580.sum
  PREPARED BY BIB FROM INPUT FILE a:bib580.in

      SUMMARY REPORT

( 1)X( 2) = 3- 3 X 3- 5 Coeff= -.3107;
( 1)X( 3) = 3- 3 X 3- 7 Coeff= .0000;
( 1)X( 4) = 3- 3 X 3- 9 Coeff= .0000;
( 1)X(17) = 3- 3 X 25- 1 Coeff= .0000;
( 2)X( 3) = 3- 5 X 3- 7 Coeff= .0000;
( 2)X( 4) = 3- 5 X 3- 9 Coeff= .0000;
( 2)X(17) = 3- 5 X 25- 1 Coeff= .0000;
( 3)X( 4) = 3- 7 X 3- 9 Coeff= .0000;
( 3)X(17) = 3- 7 X 25- 1 Coeff= .0000;
( 4)X(17) = 3- 9 X 25- 1 Coeff= .0000;
( 5)X( 6) = 10- 1 X 10- 2 Coeff= .0422;
( 5)X( 7) = 10- 1 X 11- 1 Coeff= .0228;
. . . . .
(20)X(21) = 27- 2 X 28- 3 Coeff= .0158;

USE THESE VALUES
AS REFERENCE FOR SIGNIFICANCE TESTS:
S.S.Blocks = 17.9387 with 20 d.f.
M.S.Blocks = .8969

S.S.Error = .0813 with 64 d.f.
M.S.Error = .0013

MAIN EFFECTS ORDERED

      t      t
FACT LIN-FLD Response vs.err vs.blk
10 13- 1 2.99276D+00 172.116 6.476
2 3- 5 -2.27220D+00 -130.676 -4.917
11 13- 2 2.23912D+00 128.774 4.845
5 10- 1 -2.13158D+00 -122.589 -4.613
8 11- 4 -6.90869D-01 -39.733 -1.495
1 3- 3 -6.78762D-01 -39.036 -1.469
6 10- 2 -6.61935D-01 -38.068 -1.432
9 12- 1 2.58030D-01 14.840 .558
  
```

12	14- 1	2.47964D-01	14.261	.537
14	15- 1	2.31179D-01	13.295	.500
21	28- 3	-1.87435D-01	-10.780	-.406
20	27- 2	-1.38560D-01	-7.969	-.300
17	25- 1	1.34196D-01	7.718	.290
4	3- 9	1.32595D-01	7.626	.287
3	3- 7	1.28988D-01	7.418	.279
19	27- 1	1.27845D-01	7.352	.277
18	25- 2	1.23988D-01	7.131	.268
16	15- 3	1.19839D-01	6.892	.259
7	11- 1	-9.76726D-02	-5.617	-.211
15	15- 2	6.76726D-02	3.892	.146
13	14- 2	5.48274D-02	3.153	.119

PROGRAM DESCRIPTION:
DATA AND DESCRIPTOR FILES

A datafile keeps parameters that require changes. This file should contain all the "neutral," that is, the built-in settings for each of the parameters. The SOYGRO prototype has one such file named SOY50.DAT. This file is in free format with blanks between numbers. There are four parameters (fields) in the first line, three in the second line, and so forth. The values for the first line, 48.27, 40.30, 1.67, and -0.0173, are the "neutral" values of the given parameters. The following listing gives the data in SOY50.DAT:

```

48.27 40.30 1.67 -0.0173
-1.599 1.132 -0.123
0.0 0.0 5.00 0.0 24.0 1.0 34.0 1.0 45.00
  0.0 50.0 0.0
1.50 1.77 30
0.0 0.0 0.1 0.1243 0.2 0.1917 0.3 0.2564
  0.4 0.3183 0.5 0.3773
0.6 0.4336 0.7 0.4870 0.8 0.5376 0.9
  0.5855 1.0 0.6305 1.1 0.6728
1.2 0.7122 1.3 0.7488 1.4 0.7826 1.5
  0.8137 1.6 0.8419 1.8 0.8899
2.0 0.9267 2.2 0.9523 2.4 0.9667 2.6
  0.9717 2.8 0.9785 3.0 0.9837
3.5 0.9918 4.0 0.9959 4.5 0.9979 5.0
  0.9989 7.5 1.0000 8.0 1.0000
3.5E-04 0.0040
1.61 1.44 1.37 2.08 1.45 1.49
0.68
0.294 0.125 0.128 0.035
0.092 0.056 0.196 0.056
1.00 0.20 0.05
0.0 0.0 5.0 0.0 14.0 0.12 30.0 0.12
3.0 0.0 5.0 0.2 10.0 0.6 30.0 0.6
0.56 0.24
0.50
0.0 .368 2.0 .483 4.0 .45 5.0
  .320 30. .32
0.0 .097 2.0 .124 4.0 .31 5.0
  .460 30. .460
250. 370.
0.3 400. 230.0 171.4
0.0 0.0 1.0 18.3 2.0 48.6 3.0 99.6
  4.0 178.2 5.0 285.7
20.0 9500
0.0 0.15 3.0 0.15 6.0 0.15 30.0 0.15
78.0 0.60
14 10 0.398
-0.4495 0.125 -0.00269
30.0 7.0 45.0
  
```

6.522 10.87 2.40 1.00 9.48
 0.12 0.50
 0.83 3.6765E-5
 -2.22 -6.67

A companion to the datafile SOY50.DAT is the "Descriptor File" SOY50.DES which describes by name all the parameters found in the datafile. The "Descriptor File" gives a more detailed description for each parameter change. The layout is as follows (see SOY50.DES example):

- (1) A Header
 - (2) Line number (01) , the number of "fields" in this line here four) and, in quotes, the names of the fields. In the example, line one of the datafile (SOY50.DAT) has four fields with parameter names PARMAX, PHIMAX, PHFAC1 and PHFAC2⁶.
 - (3) One or more records describe how to modify the parameters. If no parameters in a line need changing, there is no record. Any text editor may modify these records later. The example has no detail record in line 1. Line 10, however, has two parameters subject to modification. Parameter (field) 1 which is "CH2O for respiration per day" has the low setting as 0.75 times the neutral value and 1.25 times the neutral value for the high setting. Field 2 which is "CH2O used for CH2O fixed" the low setting as 0.75 times the neutral value and 1.25 times the neutral value for the high setting. A different kind of modification occurs in line 3. Field numbers 3,5,7, and 9 require shifting. Field 3 which is "XPHOTO(2) (Temperature Reduction)" has the low setting as the neutral value minus 1 and the high setting as the neutral value plus 4.
 - (4) A trailer record for each line of the data file: 99 '*END*' 0 0
- Steps (2) through (4) repeat for each line of the datafile.

The descriptor file corresponds to the program documentation provided by the University of Florida researchers. The example for lines 3 and 10 above follows:

```

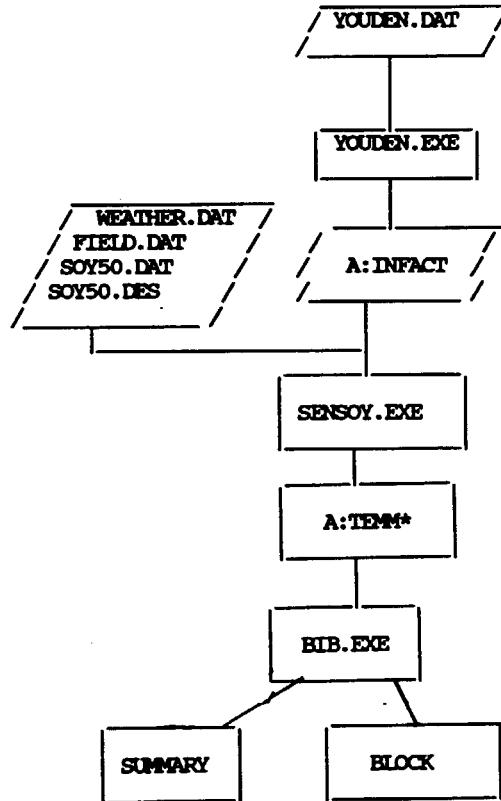
.....
03 12 'XPH(1)' 'YPH(1)' 'XPH(2)' 'YPH(2)'
      'XPH(3)' 'YPH(3)'
      'XPH(4)' 'YPH(4)' 'XPH(5)' 'YPH(5)'
      'XPH(6)' 'YPH(6)'
3 'XPHOTO(2) TEMPERATURE REDUCTION' -1 +4
5 'XPHOTO(3) TEMPERATURE REDUCTION' -2 +2
7 'XPHOTO(4) TEMPERATURE REDUCTION' -2 +2
9 'XPHOTO(5) TEMPERATURE REDUCTION' -2 +2
99 '*END*' 0 0
.....
10 2 'RES30C' 'R30C2'
1 'GM CH2O FOR RESPIRATION /DAY' 0.75 1.25
2 'GM CH2O USED FOR CH2O FIXED' 0.75 1.25
99 '*END*' 0 0

```

1 SOYGRO is the plant process model developed at the University of Florida (see Wilkerson, and others) that is the prototype for the development of procedures of this document.

- 2 The variable names assigned to such parameters in global (named COMMON) files could be read at the time of compilation of each subprogram.
- 3 Only the first and last of the 21 blocks are reproduced here.
- 4 Only the beginning and end of the file are reproduced below.
- 5 This program is a standard balanced incomplete block analysis program.
- 6 Note the free format with one or more blanks between fields and characters in single quotes.

BALANCED-INCOMPLETE-BLOCK
 PROGRAM FLOW



NOTE * : TEMM may be called any acceptable file name.

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