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SOFTWARE

A Computer Program to Analyze Single-Season Crop Model Outputs

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ABSTRACT

Computer simulation models of the growth, development, and yield of annual crops can produce large quantities of data, especially if a simulation experiment involves many treatments and replications across different years. Computer software was written to perform simple analyses of such experiments, allowing the user to identify those treatments that are productive, stable, economically attractive, environmentally sound, or otherwise suitable for the purposes of the investigator. The computer program, which runs on a DOS (IBM-compatible) personal computer, can interface with output files produced by any crop model run on any other computer that conforms to a common output file structure. Summary statistics for a wide variety of model output variables are calculated and presented to the user in a number of tabular and graphical forms. Net monetary returns and gross margins can also be calculated, and price-cost variability can be taken into account in the analysis. The user can perform an economic comparison of simulation treatments using mean-Gini stochastic dominance or, visually, mean-variance analysis. The results of all calculations and analyses are written to an output file that can be manipulated by the user to provide input to a spreadsheet or statistical package for further analysis of the simulated data. The program allows rapid, preliminary analysis of treatments from replicated simulation experiments and can help the user to identify particularly promising treatments that warrant further evaluation.

MANAGEMENT-ORIENTED CROP MODELS, such as those associated with the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project, have a number of uses. These include the screening or assessment of management options given particular environmental conditions and resource constraints at the farm level. Such assessments can be performed by running simulation experiments that may involve many treatments and many replications across different years to quantify the production risk associated with different weather patterns. Large amounts of model output data can be produced from such simulation experiments. The user is then faced with the task of analyzing these outputs in some way, to produce useful information for helping to make decisions.

A number of integrated crop modeling packages exist, although these vary in the types of analysis of model outputs that can be obtained within the package. The Century model (Parton et al., 1992) is a general model of the plant-soil ecosystem that can be used to investigate carbon and nutrient dynamics in ecosystems over a number of years. The model allows a wide variety of outputs to be graphed. PLANTGRO (Hackett, 1991) is a general plant growth package, but has little analytical capability at present. The Decision Support System for Agrotechnology Transfer (DSSAT) Version 2.1 (IBSNAT, 1989) has the capability to analyze multiple simulation treatments in simple economic terms (Godwin et al., 1990). The DSSAT, because of the daily time-step used by the crop simulation models in the package (Hoogenboom et al., 1992), can be used to investigate day-to-day crop management issues.

Crop simulation models have been used in concert with many techniques of economic analysis. Examples include dynamic optimization and linear programming models (Johnson et al., 1991), models of economic net return to different irrigation schedules (Boggess and Ritchie, 1988; Bosch and Ross, 1990) and other management factors (Alcoilja and Ritchie, 1990), risk and uncertainty analysis (Gold et al., 1990; King et al., 1988), and gross margin analysis involving multivariate optimization (Thornton and MacRobert, 1994). Well-validated crop models can help to specify the relationships between agricultural input use and resultant output that are needed in such economic analyses. Such analyses as these, however, are often complex and time-consuming, and have rarely been incorporated within a software package that is flexible and user-friendly.

This paper describes software that performs simple, rapid appraisals of the results of computer-based simulation experiments involving annual crops. The experiments may consist of many replicates and treatments. Summary statistics for model outputs can be calculated and graphed by treatment. Simple economic analyses of net returns or gross margins can also be performed, enabling the user to compare and contrast different management scenarios. The primary objective of the software is to help users identify management scenarios that appear to be particularly promising for a particular environment and that warrant further evaluation.

The software is intended for users of crop simulation models, especially those who would apply crop models to investigate specific production problems. It could also be of use to model developers, in allowing rapid appraisal of sensitivity analyses designed to identify possible problems in model specification, for example.

The software was designed as part of IBSNAT's Decision Support System for Agrotechnology Transfer. Version 2.1 of this software comprises a set of annual crop simulation models and a database management system, together with utilities and analysis programs (IBSNAT, 1989; Jones et al., 1990). It can be used for storing information concerning field trials, extracting data from crop, soils, and weather databases in a format suitable for the simulation models, running the crop models for purposes of validation or comparing management strategies, and performing simple analyses of the results of simulation runs. An upgraded version of DSSAT, to be released as Version 3, will offer substantial changes compared with

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Abbreviations: CGA, color graphics adapter; CPF, cumulative probability function; DSSAT, Decision Support System for Agrotechnology Transfer; EGA, enhanced graphics adapter; EV, mean-variance; HPGL, Hewlett-Packard graphics language; IBSNAT, International Benchmark Sites Network for Agrotechnology Transfer; IFDC, International Fertilizer Development Center; MGSD, mean-Gini stochastic dominance; RAM, random access memory; VGA, video graphics adapter.

Version 2.1 (Jones, 1993). The major improvements in the analysis software compared with that in DSSAT Version 2.1 are the incorporation of price-cost variability for economic analyses, simplified strategy evaluation procedures, and enhanced graphics capabilities. Although the program is an integral part of the DSSAT and analyzes outputs from the IBSNAT crop models, it can also be run in a stand-alone mode. The outputs from any other crop simulation model can thus be analyzed by the program, if the outputs are formatted in an appropriate way.

PROGRAM DESCRIPTION

The primary objective of the program is to allow the user to compare and contrast the different treatments that make up a simulation experiment run using simulation models of annual crops. An entire experiment may be made up of a number of treatments (such as planting date by N application regime), and the experiment may involve replication, across different years and different sites, of crop growth, development, and yield during one growing season. The weather data that drive the crop model may be historical, or they may be simulated by using a statistical weather generator. Replication across different years allows the effects of weather-related risk to be isolated and quantified. The program allows the user to assess, primarily in graphical terms, the various treatments that make up the simulation experiment. The assessment can be made by the user in terms of what is of interest, such as absolute or relative yield levels, yield risk, N loss through leaching, or economic returns of the various treatments. The program would normally be used as the first step in an analysis of a particular simulation experiment. Many users will want to investigate particular aspects further. For this reason, the results of all analyses and calculations performed during one session with the program are collected together into a file that can be manipulated by the user and used as input to other computer programs. For example, a spreadsheet could be used to generate different graphs, or statistical tests could be carried out on model outputs, if required.

A simplified diagram of the program and associated input-output files is shown in Fig. 1. The program as a whole is made up of two executable modules, one that

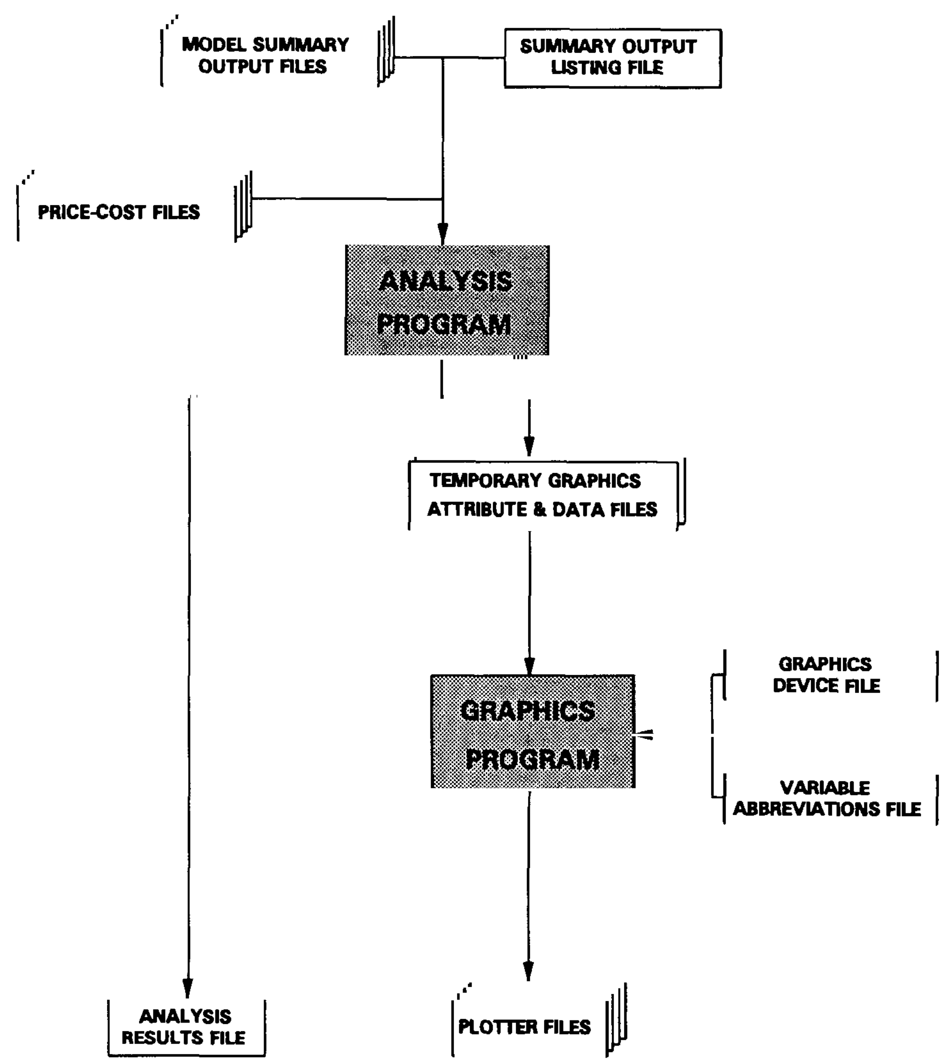

Fig. 1. Input and output files for the analysis and graphics programs.

Table 1. Input and output files associated with the analysis and graphics program for appraisal of model outputs from computer-based simulation experiments involving annual crops.

File	Name†	File type	Description
Model summary output	????????.??S	ASCII	Simulation results, stored as one run per record
Summary output listing	SEASONAL.LST	ASCII	List of model summary output files in the current directory
Price-cost file	????????.PRI	ASCII	Price-cost file for analyzing the experiment
Analysis results file	????????.??R	ASCII	Output file from the analysis program, containing analysis results and calculations
Graphics device file	GRAPH.INI	ASCII	Contains options for hardcopy graphics output in terms of printer, plotter, port, scaling, plotter language, and destination
Variable abbreviations file	DATA.CDE	ASCII	Contains all variables available for plotting from the package as a list of 4-character codes, legend, and full variable description
Graphics attribute file	GRA.OUT	ASCII	Temporary file output by analysis program and read by graphics program, describing the type of graph to be plotted
Graphics data file	DATA.DAT	ASCII	Temporary file output by analysis program and read by graphics program, containing the data to be plotted
Plotter files	??????dd.???	HPGL or PostScript	Optional file output by graphics program, containing plot commands for sending to a plotter

† In filenames, a question mark represents any alphanumeric character, and a lowercase letter *d* represents any digit (numeric character, 0 to 9).

performs the analyses and one that generates graphics. These graphics are produced interactively; whenever the user requests a graph, the analysis program writes out two temporary files, one a graphics attribute file that describes the type of graph to be plotted and the other a data file containing the data to be plotted. The analysis program then issues a DOS command to run the graphics program (i.e., the analysis and graphics programs both reside in the computer's memory at the same time). The graphics program reads the attribute and data files, plots the graph, then returns control to the analysis program.

Input and Output Files

The analysis and graphics programs require and produce a number of files (Table 1). Four of these files are briefly described below.

1. Model Summary Output File

This file contains the results of the simulation experiment, with one replicate of one treatment per record. The crop models should be run so that the summary output file contains contiguous blocks of replicates by treatment. Thus if the user has run an experiment involving three treatments, each replicated five times, then the first data record of the file contains the output from Treatment 1, Replicate 1; the second, Treatment 1, Replicate 2; and so on. The variables that are output to this file are listed in Table 2, and a full description of its format is given in Jones et al. (1994).

2. Summary Output Listing File

This file contains a list of the model summary output files in the current directory. When running the analysis program in a stand-alone mode, this file needs to be updated manually by the user. Its name is required to be SEASON.LST, and its format is as shown in Table 3.

3. Price–Cost File

For the user to perform economic analyses, the program requires access to a file detailing the prices and costs to use for each treatment for a particular simulation experiment. This file is in sections headed by an appropriate two-character crop code, and may be subdivided to provide different sets of costs and prices for each treatment in the experiment. The price–cost file is required to have the extension PRI. Each section of the price–cost file contains five lines: a header line identifying the treatment number or with the key word ALL (specifying that all treatments involving the particular crop will share the same set of prices and costs); the distribution type for each of the 11 prices and costs set out in Table 4; and three lines

Table 2. Variables written to the summary output file.

Variable no. and name	Description (format)
1 SDAT	Simulation starting date (YRDOY)†
2 PDAT	Planting date (YRDOY)
3 ADAT	Anthesis date (YRDOY)
4 MDAT	Physiological maturity date (YRDOY)
5 HDAT	Harvest date (YRDOY)
6 DWAP	Weight of planting material, kg DM ha^{-1}
7 CWAM	Weight of plant tops at maturity, kg DM ha^{-1}
8 HWAM	Yield at maturity, kg DM ha^{-1}
9 HWAH	Yield at harvest, kg DM ha^{-1}
10 BWAH	Dry wt. of harvested by-product, such as straw, kg DM ha^{-1}
11 HWUM	Harvest product individual weight, mg DM
12 H#AM	Harvest product number at maturity, no. m^{-2}
13 H#UM	Harvest product number per unit at maturity, no. unit^{-1}
14 IR#M	Irrigation applications during the season, no.
15 IRCM	Total seasonal irrigation applied, mm
16 PRCM	Total seasonal precipitation, mm
17 ETCM	Total seasonal evapotranspiration, mm
18 ROCM	Total seasonal surface runoff, mm
19 DRCM	Total seasonal water drainage, mm
20 SWXM	Extractable soil water in the profile at maturity, cm
21 NI#M	Nitrogen applications during the season, no.
22 NICM	Total inorganic nitrogen applied, kg ha^{-1}
23 NFXM	Total nitrogen fixed during the season, kg ha^{-1}
24 NUCM	Nitrogen uptake by the plant during the season, kg ha^{-1}
25 NLCM	Nitrogen leached from profile during the season, kg ha^{-1}
26 NIAM	Soil inorganic nitrogen at maturity, kg ha^{-1}
27 CNAM	Nitrogen content of plant tops at maturity, kg ha^{-1}
28 GNAM	Harvestable product nitrogen content at maturity, kg ha^{-1}
29 RECM	Total crop residue applied, kg ha^{-1}
30 ONAM	Organic soil nitrogen at maturity, kg ha^{-1}
31 OCAM	Organic soil carbon at maturity, t ha^{-1}
32 PO#M	Phosphorus applications during the season, no.
33 POCM	Total phosphorus applied, kg ha^{-1}
34 CPAM	Phosphorus in the plant tops at maturity, kg ha^{-1}
35 SPAM	Soil phosphorus content at maturity, kg ha^{-1}

† YRDOY is the date expressed as a two-digit year number followed by the three-digit day of year; e.g., 21 Feb. 1987 is expressed as 87052.

Table 3. Format of the summary output listing file that lists available summary output files, one file per record.

Columns	Description
1–2	A unique 1- or 2-digit number for each record
4–11	Filename of the summary output file, up to eight characters
13–15	A three-character code associated with the experiment
17–72	Space for comments on the nature of the experiment (optional)

of parameters describing the distribution assigned to each price and cost. Each price and cost may be fixed (deterministic) or described by a uniform, triangular, or normal distribution. If no price–cost file exists, then the software will generate a default file. The default file can then be edited from within the software package.

4. Analysis Results File

This output file stores all calculations and analysis results of a session with the analysis program for subsequent manipulation by the user. The file is 80 characters wide, facilitating editing as required.

Program Operation

The program can analyze summary output files with a maximum of 30 replicates of 20 treatments (i.e., 600 separate simulation runs). The user selects a model output file from those listed in the summary output listing file, and can then select from among a number of options: to quit, to select a new model-produced file for analysis, to select options for changing the way in which hardcopies of graphs are produced, and to assess the treatments of the experiment in terms of biophysical or economic outputs (Fig. 2).

The user may select any one of the 35 model-generated output variables listed in Table 2 (these output variables are specific to the IBSNAT crop models, but other variables produced by other crop models may be substituted for those shown). After one is selected, the program calculates the mean, standard deviation, minimum, and maximum values of all replicates and tabulates these by treatment. The user can then proceed to graph these results in three ways: as a percentile or box plot, where the 0th, 25th, 50th, 75th, and 100th percentile of the distribution of the output variable is plotted against treatment; as a cumulative probability function (CPF) plot, where the distribution is ordered from smallest to largest value and plotted against equal increments of cumulative probability (a maximum of 6 CPFs is allowed per plot to avoid congestion); and as a mean-variance plot, where the mean of the distribution of each treatment is plotted against its variance.

Economic Analysis

For an economic analysis, the user may select the price–cost file to use, edit the prices and costs to be used, and carry out the analysis. As noted above, if a price–cost file does not exist, a file with default values will be created. When prices and costs are changed from within the program (this can be done for all treatments simultaneously, or treatment by treatment), the changes are not written to the price–cost file. This is exactly analogous to sensitivity analysis in the IBSNAT crop models, where the user may investigate the effects of interactive changes to model inputs; these changes are not written to the appropriate model input file either. The results of the economic analysis are presented in tabular and graphical forms.

The user may choose to include price and cost variability in the economic analysis, since production costs and product prices may not be known with certainty. The analysis then proceeds by combining the simulated distributions of crop model outputs with distributions of costs and prices that are specified by the user in the price–cost file.

For example, suppose we have a probability distribution of simulated yields and a probability distribution for product price. To calculate total monetary returns (the quantity *price times yield*), these probability distributions have to be combined somehow. The method used is illustrated in Table 5 for a simulated yield distribution made up of seven replicates. The first step is to order the simulated yield distribution from smallest to largest. Second, five equally-spaced percentiles from the cumulative distribution function of the relevant price or cost are calculated. As in Table 5, assume that grain price is described by a triangular distribution with a minimum value a, a maximum c, and a mode or most likely value b. The values of the product price corresponding to the five percentiles of the product price triangular distribution are then found from the following:

if

$$F(\mathbf{x}) < (b - a)/(c - a)$$

then

$$\mathbf{x} = a + [F(\mathbf{x})(c - a)(b - a)]^{1/2};$$

Table 4. Costs and prices used in economic analysis. Gross margin or net return calculated as GM = $C_1X_1 + C_2X_2 - C_iX_i$, i = 3, . . . , 11.

No.	Variable: C_i	Unit	Model output: X_i†	Unit
1	Price of grain	$ t^{-1}	Harvested yield (HWAH, Var. 9)	t ha^{-1}
2	Price of by-product‡	$ t^{-1}	By-product yield (BWAH, Var. 10)	t ha^{-1}
3	Base production costs§	$ ha^{-1}	–	–
4	N fertilizer cost	$ kg^{-1}	Inorganic N applied (NICM, Var. 22)	kg ha^{-1}
5	Cost per N fertilizer application	$	N applications (NI#M, Var. 21)	no.
6	Irrigation costs	$ mm^{-1}	Irrigation applied (IRCM, Var. 15)	mm
7	Cost per irrigation application	$	Irrigation applications (IR#M, Var. 14)	no.
8	Seed cost	$ kg^{-1}	Weight of planting material (DWAP, Var. 6)	kg ha^{-1}
9	Organic amendments	$ t^{-1}	Residue applied (RECM, Var. 29)	t ha^{-1}
10	P fertilizer cost	$ kg^{-1}	P applied (POCM, Var. 33)	kg ha^{-1}
11	Cost per P fertilizer application	$	P applications (PO#M, Var. 32)	no.

† Model output codes (in parentheses) match the variable names in Table 2; variable numbers from Table 2 are added here for ease in cross-referencing.
‡ Straw or stover, for example.
§ Costs of production such as labor, fuel, etc.

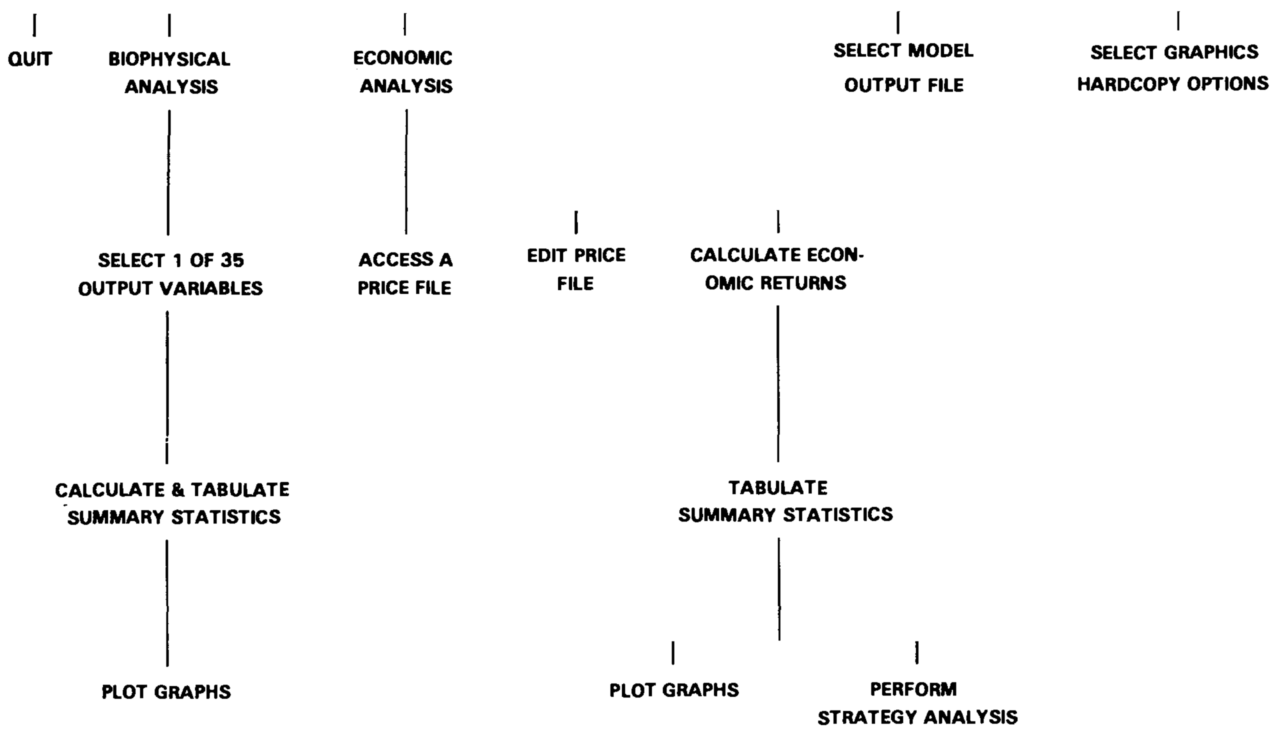

Fig. 2. Simplified diagram of program options.

else if

$$F(\mathbf{x}) \geq (b - a)/(c - a)$$

then

$$\mathbf{x} = c - [(1 - F(\mathbf{x}))\ (c - a)(c - b)]^{1/2},$$

where $F(\mathbf{x})$ is the value of cumulative probability and $\mathbf{x}$ is the associated value of the random variable (here, product price in \$ ha^{-1}) (Johnson and Kotz, 1970).

The third step is to multiply each value of simulated yield by each of the five prices; this forms a vector of length 35 in the example. This vector is then ordered from smallest to largest. Finally, linear interpolation of this vector is carried out to produce a distribution of the random variable *price* × *yield* that has the same number of members, and hence the same values of cumulative probability, as the original simulated yield distribution (in the example of Table 5, there are seven members).

This process is repeated for each stochastic price or cost until the complete distribution vector of gross margin or net return is produced. This approach to the algebraic combining of probability distributions falls into the class of methods characterized as "brute force" by Anderson and Doran (1978), but it is not dependent on the form or shape of the distributions involved.

Once the distribution of economic returns has been calculated, strategy analysis is carried out, if the user requires it. Strategy analysis allows the user to compare treatments in economic terms, taking account of weather- and price-related risk. This can be done by visual examination of the mean-variance plots of gross margins or net returns per hectare, or it can be done formally using mean–Gini stochastic dominance. Both of these methodologies, which were developed to tackle the problem of portfolio selection in investment theory, involve a pairwise comparison of random variables that, strictly speaking, should relate to financial gains and losses. The result of the analysis is an *efficient set* that contains a subset of treatments that

Table 5. Method for combining a simulated yield distribution with a grain price distribution.

Step no.	Description and sample data							
1	Order the seven-member simulated yield distribution from smallest to largest:							
	yield Y, t ha^{-1}	0.90	1.60	1.90	2.10	2.40	2.50	3.1
2	Assume grain price is described by a triangular distribution with minimum value \$90 t^{-1}, mode \$110 t^{-1}, and maximum value \$120 t^{-1}; calculate the following percentiles from the inverse of the triangular distribution:							
	percentile	0.0	25.0	50.0	75.0	100.0		
	price P, \$ t^{-1}	90.0	102.2	107.3	111.3	120.0		
3	Multiply each yield by each of the five price percentiles to form a vector of length 35; then order this from smallest to largest:							
	n	1	2	3	4	...	34	35
	P × Y	81.00	91.98	96.57	100.17	...	345.03	372.00
4	From the distribution of P × Y, described by 35 values, calculate by linear interpolation the following percentiles of the distribution, so that for seven values of yield, we obtain seven values of P × Y:							
	percentile	0.0	16.7	33.3	50.0	66.7	83.3	100.0
	P × Y	81.00	153.76	192.73	225.00	254.33	282.00	372.00

are economically superior, in the sense that they would be preferred over inefficient (dominated) treatments by decision makers who act in accordance with a set of largely reasonable axioms (Anderson et al., 1977). These methodologies are briefly described.

Mean-Variance (EV) Analysis

For two risky prospects **A** and **B**, with means $E(.)$ and variances $V(.)$ respectively, then **A** dominates **B** if

$$E(\mathbf{A}) = E(\mathbf{B}) \text{ and } V(\mathbf{A}) < V(\mathbf{B})$$

or if

$$V(\mathbf{A}) = V(\mathbf{B}) \text{ and } E(\mathbf{A}) > E(\mathbf{B}).$$

A is then said to be EV-efficient. If prospects are plotted in EV space (E the ordinate, V the abscissa), then their attractiveness to the decision maker increases with higher E and lower V. Among other assumptions, EV analysis assumes that the risky prospects are distributed normally or at least distributed symmetrically (Anderson et al., 1977). This is sometimes untenable, and in any case the EV criterion has fairly weak discriminatory power (i.e., the efficient sets tend to be large).

Mean–Gini Stochastic Dominance (MGSD)

For two risky prospects **A** and **B**, **A** dominates **B** by MGSD if

$$E(\mathbf{A}) \geq E(\mathbf{B})$$

and

$$E(\mathbf{A}) - \Gamma(\mathbf{A}) \geq E(\mathbf{B}) - \Gamma(\mathbf{B})$$

with strict inequality for at least one of these expressions, where $E(.)$ is the mean and $\Gamma(.)$ the Gini coefficient of distributions **A** and **B**. The Gini coefficient is half the value of Gini's mean difference, which is the absolute expected difference of a pair of randomly selected values of the variable. It is, like the variance, a measure of the spread of a probability distribution. In the software package, it is estimated by summing the differences between all possible pairs of values in the gross margin or net return vector, and taking the average. In the example in Table 5, there are thus 6 + 5 + 4 + 3 + 2 + 1 or 21 pairs of values to be considered.

Like the popular second-degree stochastic dominance rule, MGSD assumes that the decision maker is averse to risk; unlike that rule, however, it excludes the extremely risk-averse decision maker from the analysis. It is thus a more discriminating decision rule, in that the MGSD efficient set is usually smaller and, computationally, MGSD is generally much easier to establish than second-degree stochastic dominance (Buccola and Subaei, 1984; Fawcett and Thornton, 1990). The analysis program performs the appropriate calculations, tabulates the results, and identifies the efficient treatment or treatments explicitly.

RESULTS

To illustrate the use of this software package and the types of graphs that can be produced, a simulation experiment was performed with a model of the growth, development, and yield of maize (CERES-Maize, Ritchie et al., 1989), run for a site at Gainesville, FL, in rainfed conditions on a Millhopper fine sand soil (loamy, siliceous, hyperthermic Grossarenic Paleudult), made up of two experimental factors: two dates of planting (8 March and 8 April) and three levels of N fertilizer application (0, 30, and 60 kg urea ha^{-1} applied at planting). The experiment was replicated over 10 seasons using simulated daily weather records for the site obtained using WGEN (Richardson, 1985). The experimental data set included with the distribution version of CERES-Maize Version 2.1 showed that the model adequately responded to different N fertilizer and irrigation management treatments for the same site at Gainesville, FL, when model-predicted data were compared with field-measured data (Ritchie et al., 1989).

Table 6. Simulated maize yields for a six-treatment experiment.

Planting date	Urea applied	Yield			CV
		Mean	Min.	Max.	
	kg ha^{-1}	t ha^{-1}			%
8 March	0	2.54	0.00	4.23	48
	30	4.36	0.00	7.56	47
	60	5.51	0.00	7.72	39
8 April	0	3.56	2.27	4.67	21
	30	5.89	3.91	6.86	18
	60	6.32	4.69	7.02	11

The analysis program was used to identify which combination of planting date and fertilizer application gave the highest mean yield, and to isolate the effect of weather on yield variability between years. The effect of moving the planting date from 8 March to 8 April was to increase mean yield for all N levels, because at this site water availability limits maize yields in most years if the crop is planted too early (Table 6). For each planting date, the marginal mean yield increase was substantial between urea applications of 0 and 30 kg ha^{-1}, but was much less between 30 and 60 kg ha^{-1}, indicating diminishing marginal yield increments to successive urea additions. For both planting dates, urea additions decreased yield variability in terms of the coefficient of variation, although this effect was more pronounced for the later planting date.

An economic analysis was also performed, to find the probability of negative net returns for each treatment, taking yield and product price risk into account. It was assumed that the price received for maize grain was not known with certainty but could be described by a normal distribution with a standard deviation of 10% of the mean. For the costs and prices used, the highest mean net return occurred at the later planting date with 60 kg urea ha^{-1} (Table 7). As for simulated yield response, the maximum net return occurred at the earlier planting date with 60 kg urea ha^{-1}, but this treatment was riskier than the comparable treatment for the later planting date in terms of both its CV and the probability of a negative net return to the maize enterprise.

Examples of the graphs produced using the program for the above analyses are shown in Fig. 3, in terms of a CPF plot of harvest yield for each treatment and a box plot of monetary returns per hectare, and in Fig. 4, a CPF plot of monetary returns per hectare, and a mean-variance diagram of monetary returns per hectare. Visual inspec-

Table 7. Simulated net monetary returns for a six-treatment experiment.

Planting date	Urea applied	Return: Mean	Min.	Max.	$E(x) - \Gamma(x)$†	CV	Probability of negative returns
	kg ha^{-1}	\$ ha^{-1}				%	
8 March	0	35	−330	410	−81	574	0.48
	30	274	−356	965	70	130	0.12
	60	401	−379	972	195	91	0.08
8 April	0	172	−91	487	74	96	0.09
	30	463	53	842	325	50	0.00
	60	502	114	849	372	43	0.00

† $\Gamma(x)$, the Gini coefficient, is one-half the expected absolute difference between a randomly selected pair of values of x.

tion of Fig. 3a and Fig. 4a highlights the fact that incorporating price-cost variability will generally make the gross margin CPFs smoother and more like normal distributions, compared with the yield distributions themselves.

For this experiment, the EV-efficient treatments are easily identified from Fig. 4b. Treatment 5, for example, is dominated by Treatment 6, since the mean monetary return for Treatment 5 is less and its variance is greater than those of Treatment 6. Only Treatments 4 and 6 are EV-efficient. In other words, without knowing more about the decision maker's attitude to risk, we cannot distinguish between Treatments 4 and 6 using the EV criterion; Treatment 6 has a higher mean than Treatment 4, but it is also more risky, because of its higher variance.

In terms of MGSD, only Treatment 6 is mean–Gini efficient, since both $E(.)$ and the quantity $E(.) - \Gamma(.)$ for Treatment 6 exceed those of the other five treatments (Table 7).

This simplistic example showed that, providing the model

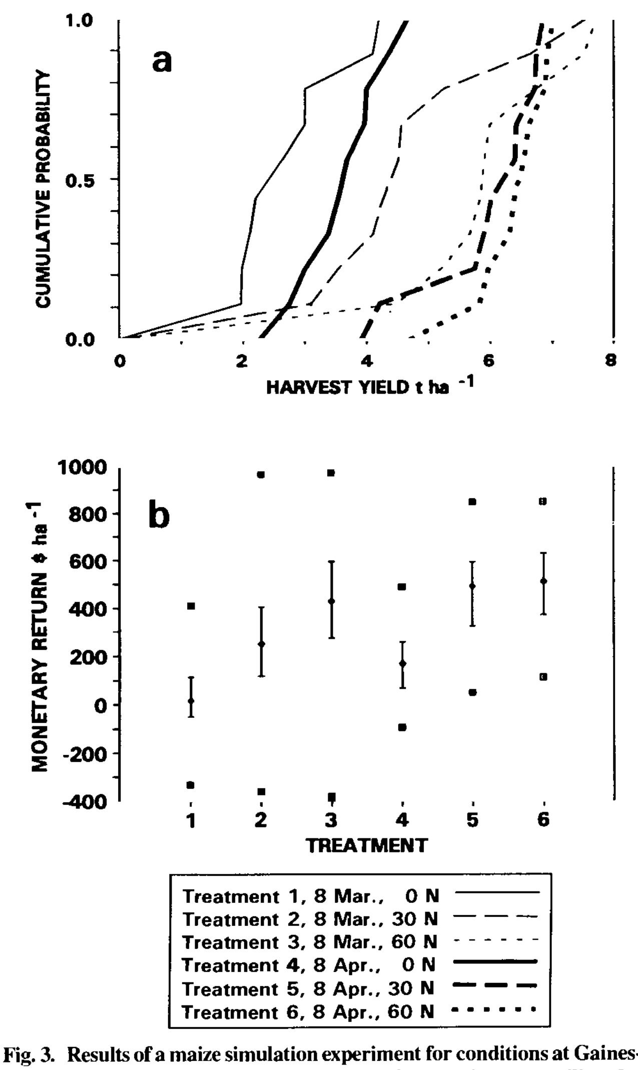

Fig. 3. Results of a maize simulation experiment for conditions at Gainesville, FL, replicated over 10 seasons. (a) Cumulative probability plot of harvest yield per hectare. (b) Box plot of monetary returns per hectare by treatment number, showing the 0th, 25th, 50th, 75th and 100th percentile of the distributions.

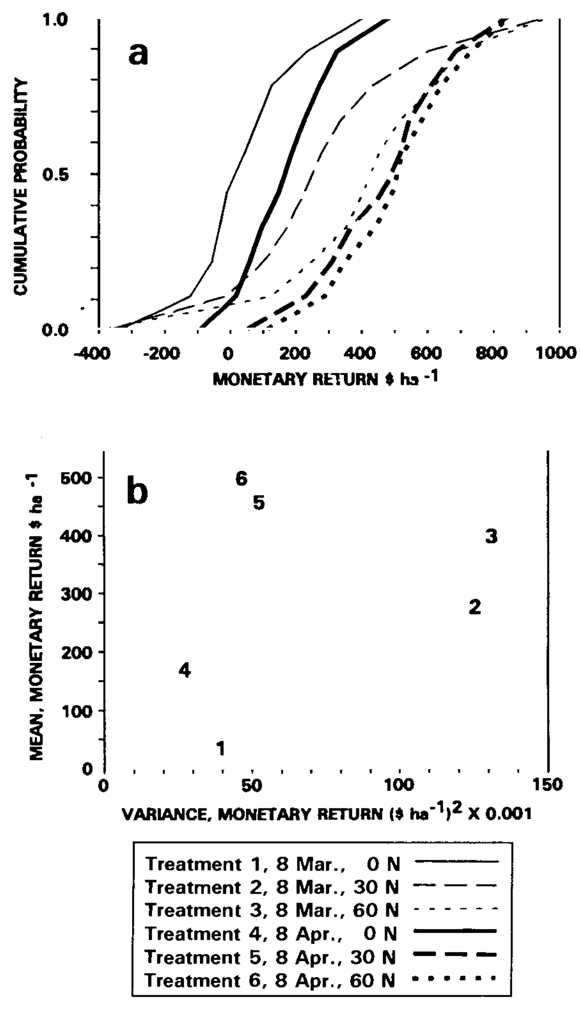

Fig. 4. Results of a maize simulation experiment for conditions at Gainesville, FL, replicated over 10 seasons. (a) Cumulative probability plot of monetary returns per hectare. (b) Mean-variance plot of monetary returns per hectare.

accurately simulated the response of maize to soil, weather, and management conditions at this location, early planting is much riskier than later planting, and that moderate additions of urea fertilizer tend to increase net returns and decrease year-to-year variability, all other things being equal.

DISCUSSION

A common objective of many simulation experiments is to screen treatment combinations to produce a small number of particularly promising combinations that warrant further investigation. The computer software described is intended to help crop model builders and users with this screening process. The analysis program offers users the facility to investigate quickly the main results of single-season simulation experiments. One of the main problems in constructing such a program is knowing how much or how little to include in the analyses. Users of simulation models are so diverse, and models are used for such diverse ends, that it is clearly impossible to cater to every conceivable need. The analyses included are those that are probably most often performed by users as a first step in analyzing the results of simulation experiments.

Documentation

More detailed documentation, including information on file structure, is given in an ASCII file distributed with the program.

Hardware and Software Requirements

The analysis program is written in FORTRAN 77 with some Microsoft[1] extensions and compiled with the Microsoft FORTRAN compiler Version 5.1. The size of the executable file is 150 Kb. The graphics program is written in Borland's Turbo Vision, and the size of the executable file is 135 Kb. Approximately 500 Kb of RAM is required to run both the analysis and graphics programs, and 1 Mb of hard disk space is ample for running the programs. The programs run under DOS 3.1 or higher. To display the graphical results, the microcomputer must have a graphics adapter (IBM CGA, EGA, VGA, or equivalent) and a color or monochrome graphics monitor with matching screen resolution. The graphs produced on the monitor can be printed on any device that can emulate one of the following printers: Hewlett-Packard LaserJet and InkJet; Epson MX, LQ, and FX; and Toshiba P series. The graphs can be plotted on any device that can handle Hewlett Packard-HPGL format or PostScript language format plots. Graphs can also be saved as a file on the hard disk in either Hewlett-Packard HPGL format or PostScript language format for later printing, plotting, or incorporation into other graphics or wordprocessing software. A mouse can be used with the package, but it is not required.

[1] Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the International Fertilizer Development Center or the University of Georgia.

Availability

The analysis and graphics programs, together with sample input files, were distributed as part of IBSNAT's DSSAT Version 3. Contact the IBSNAT Project (Dep. of Agronomy and Soil Science, Univ. of Hawaii, Honolulu, HI 96822) for information about ordering DSSAT Version 3 or these analysis and graphics programs. Potential users are reminded that the quality of the analyses obtained using the program will depend on the integrity of the model used and the quality of its input data.

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