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SENSITIVITY TESTS OF THE ENVIRONMENTAL VARIABLES IN IRRIMOD

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SENSITIVITY TESTS OF THE ENVIRONMENTAL VARIABLES IN IRRIMOD[1]

ABSTRACT

The multiple field, multiple crop, toposequence rice-based model IRRIMOD was tested for sensitivity to its climatic and soil input parameters. The climatic parameters are rainfall, solar radiation, pan evaporation, photoperiod, and maximum and minimum air temperature. Each climatic parameter except rainfall is an average daily value for each week calculated over 20 years. Twenty-one soil parameters describe the soil and field position of each field in the toposequence.

IRRIMOD was much more sensitive to climatic parameters than to soil parameters. The model was most sensitive to maximum and minimum temperature. Of the soil parameters, the model was most sensitive to hydraulic parameters such as soil water-holding capacity at saturation, field capacity, and the increase in soil percolation rate under dry seeded rice. Two parameters that describe ammonification rates were also important.

When standard soil and crop parameters were used and climatic properties were combined to reflect location differences, the model predicted a 6.6% gross income increase by moving to a 28° latitude and almost no change for the toposequence by moving to 1° latitude compared to 14° latitude. In the latter comparison, all of the fields except one in a toposequence of five fields showed a predicted yield and gross income decrease.

When changes in soil properties were combined, increased compaction caused a predicted yield and gross income decrease. Decreasing compaction increased yield and gross income for the upper fields in a toposequence but slightly decreased yield and income for lower fields. By combining soil property changes in another way, the model predicted higher yield and gross income for increases in both sand and clay content.

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SENSITIVITY TESTS OF THE ENVIRONMENTAL VARIABLES IN IRRIMOD

The multiple field, multiple crop rice-based simulation model IRRIMOD was developed by Angus (1979) and Angus and Zandstra (1980). It is a toposequence model, described by its authors as being at the

> "agronomic level . . . . . and is not intended to cover the detailed processes included in physiological models, nor to have the regional scope of economic models. An attempt has been made to try to account for the important variables affecting crop production, and not just the ones which are relatively well understood such as photosynthesis, while totally ignoring important but little researched factors."

IRRIMOD not only includes plant growth as a function of climatic and soil hydrologic properties but also attempts to account for nitrogen fertility levels and transformations. These factors are applied equally to rice as a dry seeded, wet seeded, transplanted, or ratooned crop and to the dry season crops mungbean, maize, or sorghum.

IRRIMOD is driven by the climatic parameters of daily rainfall, pan evaporation, solar radiation, photoperiod, and maximum and minimum air temperature. The soil parameters describe hydraulic properties for calculating soil water balance, parameters to describe field positions in the landscape, and variables to calculate soil nitrogen balance.

Some validation tests that compare model output to independent field data are given in Angus' publications. However, not every part of the model has been validated. The model's responses to changes in input parameters should also be tested. This is sensitivity testing or analyses. The following is a description of systematic changes that were made individually and as a combination of environmental parameters, and a discussion of some of the model's calculated outputs.

METHOD

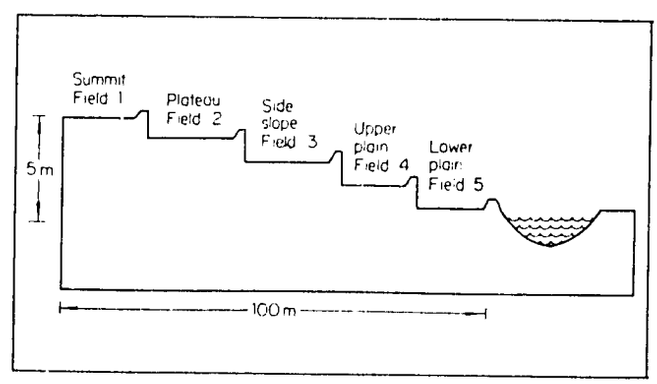
Two versions of the program were prepared. In one, the climatic variables could be changed independently or in combination and in the other soil relationship parameters could be changed independently or in combination. All other model parameters were held constant (Whisler 1983b). In any given test a percentage change of a particular variable or variables was made with all others held constant. For example, the amount of rainfall on any day could be changed but not the day of the rainfall. By changing the sign of the percentage, the magnitude of the variable could be either increased or decreased.

The crop growing season in the Philippines begins in April in the eastern part of the country and progresses steadily westward (Zandstra et al 1980). Angus' model begins 1 April and calculates the soil water balance for each field in the toposequence. A maximum of 10 fields are allowed but 5 are used here (Fig. 1). When the water balance is sufficient, the first dry seeded crop is planted and harvested, and subsequent specified crops are planted and harvested. A maximum of three crops are grown in one season.

The values of weather variables used in IRRIMOD are given in Tables 1 and 2. Table 1 gives the weekly average of daily pan evaporation, solar radiation, maximum and minimum temperature and photoperiod for 20 years from records at IRRI or the University of the Philippines at Los Baños (Angus and Manalo 1979). Table 2 is the actual daily rainfall in 1980, beginning in April, that was used in these simulations. Because these are sensitivity tests and not validation tests, the January-March data are also for 1980.

A list of soil variables and their units is given in Table 3. The standard values of soil variables for each of five fields (Fig. 1) are given in Table 4. These soil data are from toposequence fields in Oton-Tigbauan, Iloilo, Philippines (Roxas et al 1982).

The tests were made as follows: 1) climate variables were changed by ±10% and ±50%. 2) Soil variables were changed by ±20%. (A ±20% value was chosen because it would normally be large enough to detect for measurable parameters and would register change if the model is at all sensitive.) 3) Combinations of climate variables were changed to simulate other climatic zones or regions to see what the model would predict for regions north of or closer to the equator than IRRI (14°N). 4) Combinations of soil variables were changed to simulate soil textural changes and soil compaction changes.



1. Schematic diagram of toposequence used in IRRIMOD.

RESULTS AND DISCUSSION

IRRIMOD calculates several soil and crop quantities such as total aboveground biomass, grain weight, crop nitrogen accumulation, soil water content, soil ammonium and nitrate nitrogen content, planting and harvesting date, and total gross income per field. Only a few of these quantities are discussed here. Because the model is incompletely validated, many of the results will be shown as a percent change from the standard simulation (0% change in any

Table 1. Values of some weather variables at IRRI-UPLB. The values are the average daily values for each week of the year beginning 1 April (Angus and Manalo 1979).

1.	7.6	7.8	8.1	7.8	7.6	7.2	6.7	6.3	5.9	5.6	5.3	5.1	4.8
	4.7	4.6	4.5	4.5	4.5	4.5	4.4	4.3	4.2	4.2	4.1	4.1	4.1
	4.2	4.3	4.3	4.2	4.1	3.9	3.7	3.6	3.5	3.5	3.5	3.6	3.7
	3.9	4.2	4.5	4.8	5.1	5.3	5.6	5.8	6.1	6.4	6.7	7.0	7.3
2.	567	588	579	568	550	529	511	498	483	472	462	452	441
	429	418	408	398	389	382	374	376	379	382	384	385	383
	380	376	372	362	350	336	322	312	307	302	303	310	320
	332	351	370	387	408	428	443	467	484	504	521	537	553
3.	32.7	33.1	33.4	33.7	33.9	34.0	34.0	33.8	33.6	33.3	33.0	32.6	32.4
	32.1	31.9	31.7	31.6	31.5	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.3
	31.2	31.1	31.0	30.8	30.6	30.4	30.2	29.9	29.6	29.4	29.2	29.0	28.9
	28.8	28.8	28.9	29.1	29.3	29.6	29.9	30.2	30.7	31.1	31.5	31.9	32.3
4.	22.1	22.4	22.7	23.0	23.3	23.5	23.6	23.6	23.6	23.5	23.5	23.4	23.4
	23.3	23.4	23.3	23.3	23.3	23.2	23.2	23.1	23.1	23.1	23.1	23.0	22.9
	22.9	22.8	22.8	22.7	22.6	22.6	22.5	22.4	22.3	22.1	22.0	21.8	21.6
	21.4	21.0	20.8	20.6	20.5	20.6	20.7	20.8	21.1	21.1	21.4	21.6	21.8
5.	12.5	12.6	21.7	12.8	12.8	12.9	13.0	13.0	13.1	13.1	13.2	13.2	13.1
	13.1	13.1	13.0	13.0	12.9	12.9	12.8	12.7	12.6	12.5	12.5	12.4	12.3
	12.2	12.1	12.0	12.0	11.9	11.8	11.7	11.7	11.6	11.6	11.5	11.5	11.5
	11.6	11.6	11.6	11.7	11.7	11.8	11.9	12.0	12.0	12.1	12.2	12.3	12.4

1. Average daily pan evaporation (mm d^{-1}). 2. Average daily radiation (cal cm^{-2} d^{-1}). 3. Average daily maximum temperature (°C). 4. Average daily minimum temperature (°C). 5. Average daily photoperiod (h d^{-1}).

Table 2. Rainfall (mm) at IRRI as reported by the Agroclimatic Service Unit for 1980.

Day	Rainfall (mm)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1		1.3	0.2	1.0		0.8	11.2	126.5	11.4			
2						2.8	8.4	52.6		0.8		
3			4.3	3.3	1.5	0.2	1.0	4.1	0.2			
4	0.8		10.9	7.4		1.0						
5	0.5		4.1	30.2	3.3	29.0			2.5		1.5	
6	0.8		1.3					17.3		1.0	1.0	
7	13.2		1.0		0.8	1.3		5.6		1.3		
8			5.6	24.4		1.5		13.7				
9			3.6	6.9	0.5	2.0	0.2	39.6				4.6
10			2.0		9.9	9.4	14.2	3.6	1.5			
11		5.6			26.4	5.8	6.1		3.3		0.2	
12		1.5			3.8	34.0	1.5		15.8		0.8	
13		1.3			34.5	13.2	0.2		23.6		11.9	
14				52.8	4.8	1.5	0.5		17.8		0.5	
15				21.3	0.2	10.4	13.5				0.5	
16				0.2		0.2		0.5				
17				1.0	7.9	10.4	6.1			11.2		
18			134.6	9.6	5.3		30.2					
19		4.3	71.1	27.7	12.4		7.4		2.0			
20		24.6	3.8	7.6	36.6	31.2	16.8		0.2			
21		113.0	10.2		3.3							
22			8.9	3.3	1.5		23.9	1.3		0.2		
23			8.1	61.5	73.7	0.5	0.5					14.6
24		1.5		71.4	3.5		3.0			1.3		92.5
25		18.0			1.0	0.2	194.1		1.0			2.3
26	0.8		5.1		19.3		46.9					
27					3.8	8.9			2.8	0.2		6.9
28			20.3		0.2			12.4	1.3			0.5
29			51.3	0.8	6.9	0.2	9.6	0.2				0.2
30		4.1	4.1	8.4	11.7		20.6	11.4		1.0		0.8
31		18.5			14.0		5.1		0.5			

variable). Table 5 gives some of the results of the standard simulation. The cropping sequence was dry seeded rice (DSR), transplanted rice (TPR), followed by mungbean if there was sufficient soil moisture.

Grain yield is a function of the crop biomass and stresses it has undergone (Angus 1979). The upper limits for plant biomass are 11 t ha^{-1} for rice and 4 t ha^{-1} for mungbean. These limits are below the IRRI experiment station maximum, but are generally higher than farmer levels (Angus, pers. comm.).

Table 3. Soil variables used and tested in IRRIMOD.

Variable	
K1	Height of field above datum level (m)
2	Perched water when puddled zone is saturated (mm)
3	Percolation rate when puddled zone is saturated (mm d^{-1})
4	Seepage rate when puddled zone is saturated (mm d^{-1})
5	Depth of water table at its deepest extent (m)
6	Soil water in fully saturated profile-excluding perched water (mm)
7	Soil water in drained subsoil (mm)
8	Soil water in drained subsoil depleted by upland crop (mm)
9	Coefficient of upflow from subsoil to puddled soil (D-less)
10	Saturated lateral conductivity of subsoil (mm M m^{-1})
11	Maximum amount of ammonification in puddled zone in a year (kg N ha^{-1})
12	Constant of curvature for ammonification in puddled soil $°C^{-1}$
13	Half-life of NO_3 in a flooded soil (days)
14	Perched water when rice dies in puddled soil (mm)
15	First stage soil evaporation (mm)
16	Second stage soil evaporation for puddled soil (mm d^{-1} to -0.5)
17	Perched water required for dry seeding (mm)
18	Starting value of perched soil water (mm)
19	Starting value for soil water (mm)
20	"Field capacity" for puddled soil (mm)
21	Ratio by which percolation rate increases with DSR

Table 4. Standard parameter values for each of 5 fields in the toposequence.

K	Field 1 (summit)	Field 2 (plateau)	Field 3 (side slope)	Field 4 (upper plain)	Field 5 (lower plain)
1	5.0	4.0	3.0	2.0	1.0
2	150.0	150.0	150.0	150.0	150.0
3	7.0	1.1	9.0	1.1	1.5
4	.1	1.1	9.0	1.1	1.5
5	2.5	2.3	2.2	2.0	1.5
6	1000.0	1000.0	1000.0	1000.0	1000.0
7	700.0	700.0	700.0	700.0	700.0
8	500.0	500.0	500.0	500.0	500.0
9	5.0	5.0	5.0	5.0	5.0
10	50.0	50.0	50.0	50.0	50.0
11	25.0	35.0	45.0	45.0	45.0
12	3.5	3.5	3.5	3.5	3.5
13	3.0	3.0	3.0	3.0	3.0
14	60.0	60.0	60.0	60.0	60.0
15	10.0	10.0	10.0	10.0	10.0
16	5.0	5.0	5.0	5.0	5.0
17	85.0	85.0	85.0	85.0	85.0
18	70.0	70.0	70.0	70.0	70.0
19	675.0	675.0	675.0	675.0	675.0
20	110.0	110.0	110.0	110.0	110.0
21	1.5	1.5	1.5	1.5	1.5

Climatic variables

IRRIMOD simulates dry grain weight as kg ha^{-1}. The percent changes in grain weight caused by altering climatic variables are given in Table 6 for each field and crop and in Figures 2-4 for each crop in field 5. Small changes in rainfall (±10%) usually produced small changes in the predicted yield (±7%); larger (±50%) changes generally produced larger changes in the predicted yields, following a monotonic pattern. That is, a 50% increase or decrease in rainfall would predict a larger increase or decrease in yield than a 10% change in rainfall (see also Fig. 2). In some cases, changes in predicted yield were more than proportional to the rainfall change. For example, a 10% decrease in rainfall for DSR in field 3 (side slope) predicted a 4.5% decrease in yield, while a 50% decrease in rainfall predicted a 58% decrease in yield. Most changes in yield were of the same algebraic sign as the rainfall change. As might be expected from their landscape positions, field 1 was benefited more by increased rainfall and fields 4 and 5 were more negatively influenced by reduced rainfall.

The model was not as sensitive to pan evaporation as to rainfall. Predicted changes usually were monotonic but opposite in sign to the changes of pan evaporation (Table 6,

Table 5. Predicted crop yield for each crop on each field of the toposequence, gross income for each field, planting and harvest dates for each crop and each field from IRRIMOD for the standard case.

Crop	Yield (kg ha^{-1})	Gross income (₱ ha^{-1})[a]	Planting (day-mo)	Harvest (day-mo)
		Field 1		
Dry seeded rice	1494		1 - 6	23 - 9
Mungbean	189		24 - 9	27 -11
		2241		
		Field 2		
Dry seeded rice	3788		1 - 6	21 - 9
Mungbean	185		7 - 10	10 -12
		4714		
		Field 3		
Dry seeded rice	3387		1 - 6	22 - 9
Mungbean	188		29 - 9	2 -12
		4326		
		Field 4		
Dry seeded rice	3935		1 - 6	21 - 9
Transplanted rice	2531		1 - 10	31 -12
Mungbean	228		1 - 1	6 - 3
		7607		
		Field 5		
Dry seeded rice	4030		1 - 6	21 - 9
Transplanted rice	2530		1 - 10	31 -12
Mungbean	235		7 - 1	12 - 3
		7737		

[a]Conversion rate was ₱7.38/US$.

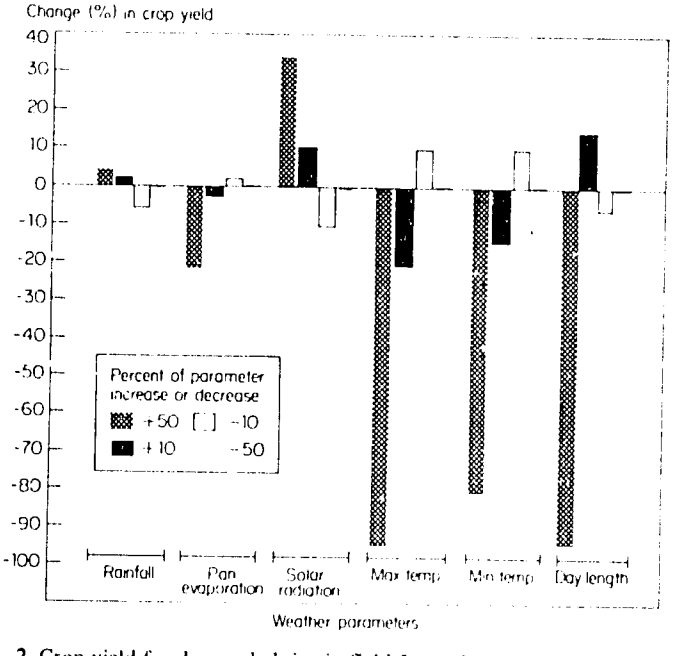
Table 6. Effect of changing weather variables on simulated crop yield as a % change from the standard.

Variable	% change of variable	Simulated crop yield as % change from standard													
		Field 1		Field 2			Field 3			Field 4			Field 5		
		DSR	Mung	DSR	TPR	Mung	DSR	TPR	Mung	DSR	TPR	Mung	DSR	TPR	Mung
Rainfall	+10	2.4	0.0	2.9	2503[a]	23.4	7.3	0.0	-0.6	3.5	0.0	0.0	2.3	-1.0	0.5
	-10	-2.0	-0.2	-6.4	0.0	0.0	-4.5	0.0	0.3	-6.5	-13.1	0.0	-6.3	0.2	-1.3
	+50	16.1	0.3	6.1	0.0	-0.8	21.3	0.0	-2.0	7.1	-2.1	5.1	4.2	-2.5	4.1
	-50	-30.6	-0.7	-30.5	0.0	0.0	-57.7	0.0	0.3	-31.0	-63.3	-100[b]	-31.1	-45.9	-100[b]
Pan evaporation	+10	-2.5	-0.2	-4.6	0.0	0.0	-4.3	0.0	0.3	-4.7	-0.2	0.0	-2.8	0.1	-1.3
	-10	3.4	0.0	3.1	2246[a]	23.4	7.7	0.0	-0.2	3.7	0.0	0.0	2.2	0.0	1.4
	+50	-16.0	-0.8	-21.7	0.0	0.0	-10.6	0.0	0.3	-23.1	-62.3	-100[b]	-22.0	0.1	-1.9
	-50	26.1	0.5	6.9	0.0	-1.0	20.5	0.0	-2.0	7.7	-1.6	3.6	4.3	-2.4	-100[b]
Solar radiation	+10	5.9	8.6	9.2	0.0	9.1	10.5	0.0	8.8	9.8	8.7	8.1	9.7	8.7	7.7
	-10	-7.1	-9.5	-11.0	0.0	-9.8	-12.3	0.0	-9.6	-11.7	-9.8	-9.0	-11.5	-9.8	-8.7
	+50	20.7	34.5	32.5	0.0	36.8	37.4	0.0	35.3	34.9	33.4	31.2	34.3	33.4	29.2
	-50	-51.3	-53.2	-69.0	0.0	-53.9	-70.5	0.0	-53.5	-70.2	-58.0	-52.5	-70.1	-58.0	-51.9
Maximum temp	+10	-9.7	-14.7	-19.4	2314[a]	9.0	-21.6	0.0	-14.5	-20.8	-8.3	-11.7	-20.6	-8.3	-9.3
	-10	3.8	9.6	10.9	0.0	12.1	12.7	0.0	10.3	11.8	-6.1	15.4	10.1	5.1	11.3
	+50	-87.0	-78.7	-94.2	729[a]	-59.3	-94.0	733[a]	-60.1	-94.5	-71.2	-66.8	-94.6	-71.3	-67.4
	-50	-29.2	3.1	-18.4	0.0	5.1	-16.4	0.0	3.4	-18.9	-100[c]	-14.4	-19.4	-100[c]	1.2
Minimum temp	+10	-6.4	-10.5	-14.6	2382[a]	13.0	-14.8	0.0	-10.4	-15.6	-5.6	-8.4	-15.4	-5.6	-6.1
	-10	4.1	7.7	9.6	0.0	7.5	10.9	0.0	8.1	10.3	1.1	10.0	10.2	2.5	6.6
	+50	-61.2	-62.0	-80.1	1314[a]	-38.4	-80.4	1121[a]	-38.4	-80.9	-48.0	-49.7	-80.9	-48.0	-47.2
	-50	-15.5	11.7	-1.1	0.0	15.2	4.3	0.0	13.1	2.0	-67.8	-100[b]	1.5	-40.9	-100[b]
Photosynthetic day length	+10	9.0	-0.6	13.9	0.0	0.0	16.9	0.0	0.0	15.1	-6.9	2.7	14.8	1.9	0.0
	-10	-2.7	0.2	-6.0	2136[a]	21.3	-5.5	0.0	0.0	-6.4	-1.7	-1.7	-6.2	-1.7	0.0
	+50	-100[b]	-100[c]	-100[b]	0.0	-100[c]	-100[b]	0.0	-100[c]	-100[b]	-100[c]	-100[c]	-100[b]	-100[b]	-100[b]
	-50	-5.0	0.3	-9.4	2469[a]	20.7	-9.4	0.0	0.0	-10.0	-2.0	-2.2	-9.8	-2.0	0.0

[a]Crop was planted in this test, but not in the standard case. [b]Crop was planted but not harvested within the same crop year. [c]Crop was not planted in this test, but was in the standard case.

Fig. 2). The lower fields were more affected by changes in evaporation than were upper fields.

Solar radiation had a slightly greater influence on the model predictions than rainfall, and changes produced by varying radiation were more symmetrical about zero than the rainfall variable (Fig. 2). As with rainfall, the predicted changes were usually of the same algebraic sign as the change in the solar radiation (Figs. 2-4). Field position in the toposequence had little effect, however.

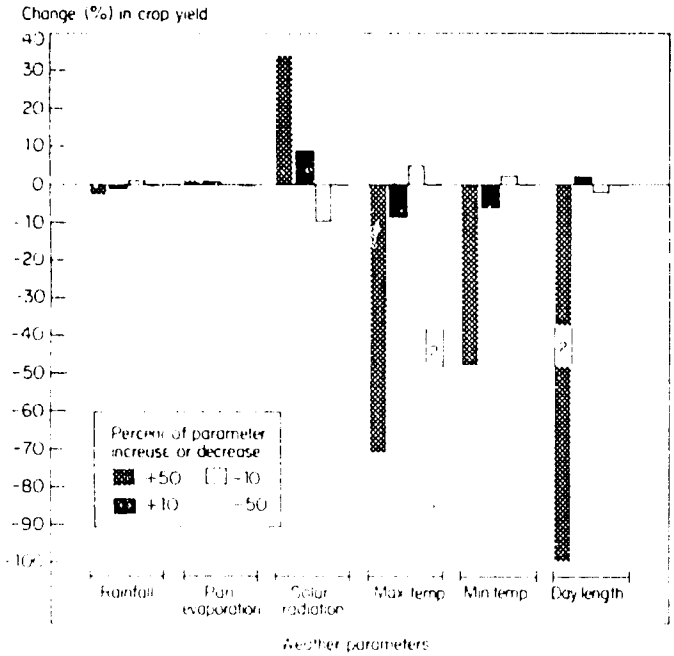


2. Crop yield for dry seeded rice in field 5 as a function of change in the weather parameters.

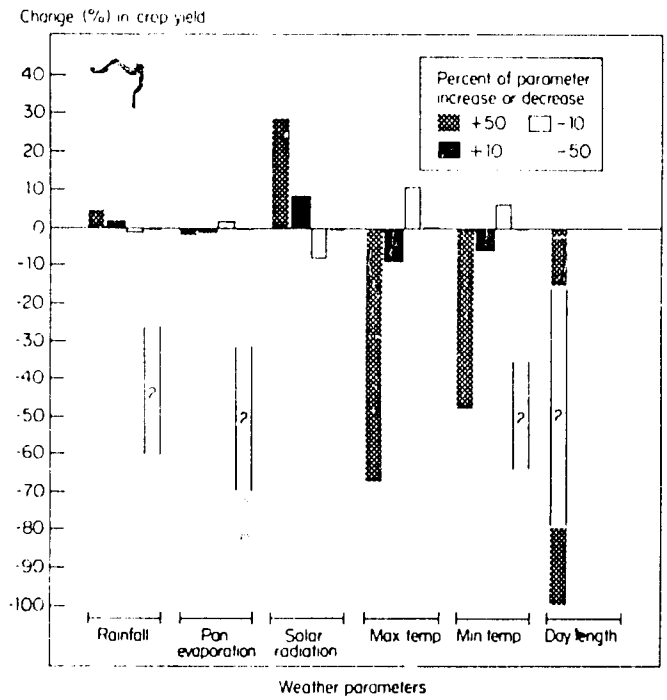
IRRIMOD often is more responsive to temperature changes than to changes in any other variable, and is more sensitive to daily maximum than to minimum temperatures because a 10% change was applied to each, and 10% of a larger number is larger than 10% of a smaller number. Because daily average temperature is important to many of the model's equations, changing the maximum temperature made bigger numerical changes than changing the minimum temperature. The projected yields often are changed more than the change in the temperature (Figs. 2, 4) because temperature is important in the model's phasic development, growth rate, and nitrogen transformation equations (Angus 1979).

The model was moderately sensitive to small (10%) changes in photoperiod. Larger (50%) changes often predicted crop failure. The DSR crop was most affected by changes in photoperiod with little variation over landscape position. It was grown during the longest photoperiod, causing changes in the variable to be of substantial magnitude.

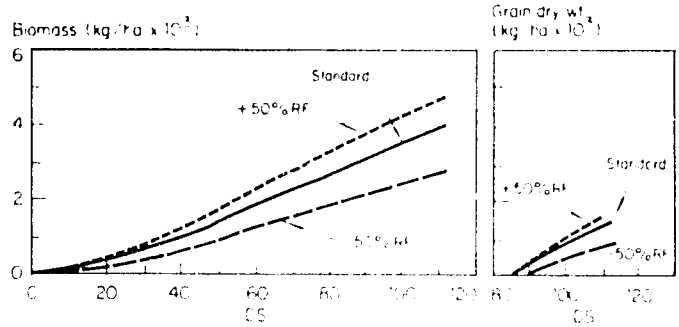
The effect of changing rainfall (RF) on predicted biomass development and grain weight for DSR and TPR are



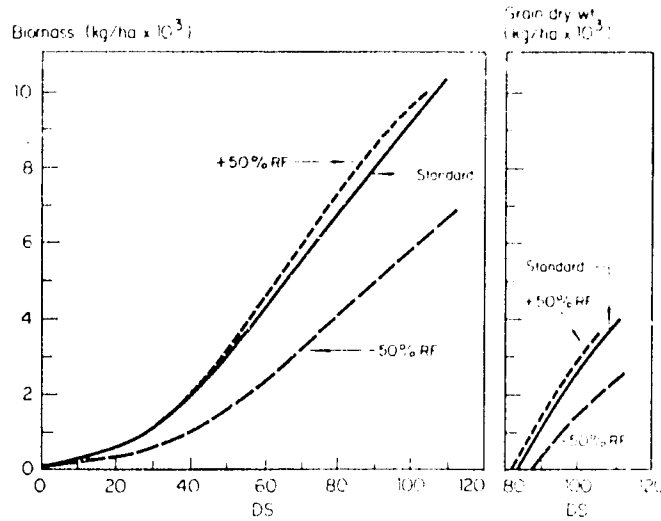
3. Crop yield for transplanted rice in field 5 as a function of change in the weather parameters. The ? stands for the fact that a crop was either planted and not harvested or not planted in this case, but was in the standard.



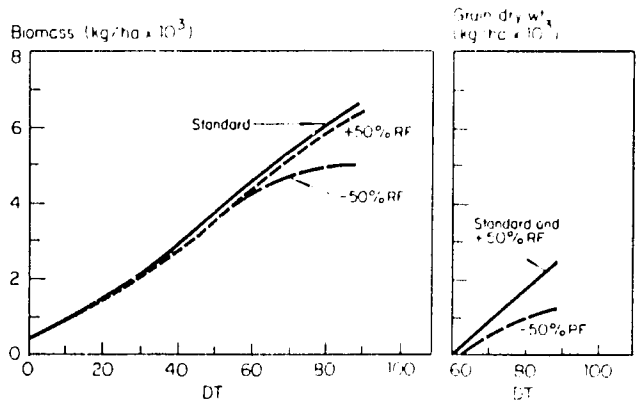
4. Crop yield for mungbean in field 5 as a function of change in the weather parameters. The ? stands for the fact that a crop was either planted and not harvested or not planted in this case, but was in the standard.



5. Biomass accumulation and grain weight accumulation for dry seeded rice in field 1 as changed by the amount of rainfall (RF). DS = days after seeding.



6. Biomass accumulation and grain dry weight accumulation for dry seeded rice in field 5 as changed by the amount of rainfall (RF). DS = days after seeding.



7. Biomass accumulation and grain weight accumulation for transplanted rice in field 5 as changed by the amount of rainfall (RF). DT = days after transplanting.

shown in Figures 5-7. Figures 5 and 6 are for DSR on fields 1 and 5, and Figure 7 is for TPR in field 5. Comparing Figures 5 and 6 shows growth rates are much faster in field 5 than in field 1, that is the slopes of the curves are steeper in Figure 6 than Figure 5. Comparing Figures 6 and 7 shows that despite a lag phase or very flat slope in Figure 6 biomass for the first 20 days after seeding (DS), the growth rate thereafter quickly becomes greater than that of the transplanted crop. Figure 7 and Table 6 show predicted reduction in grain weight and biomass for ±50% changes in rainfall. The yield and biomass reduction is to be expected for a 50% decrease in rainfall. The reduction due to a 50% in-

Table 7. Effect of changing weather variables on estimated planting (P) and harvesting (H) dates as the number of days of difference from the standard.

Variable	% change of variable	No. of days of difference from standard															
		Field 1				Field 3						Field 5					
		DSR		Mung		DSR		TPR		Mung		DSR		TPR		Mung	
		P	H	P	H	P	H	P	H	P	H	P	H	P	H	P	H
Rainfall	+10	0	0	0	0	0	+ 1	0	0	− 3	3	− 4	− 4	− 4	− 4	− 1	− 1
	−10	0	− 1	− 1	− 1	0	− 1	0	0	+ 2	+ 3	0	0	0	0	+ 3	+ 3
	+50	+1	+ 2	+ 2	+ 2	+1	+ 2	0	0	−11	−11	−17	−18	−16	−16	−10	−10
	−50	0	− 4	− 4	− 4	0	− 4	0	0	+ 2	+ 2	0	− 4	−28	−30	−77	*a*
Pan evaporation	+10	0	− 1	− 1	− 1	0	0	0	0	+ 2	+ 2	0	0	0	0	+ 3	+ 3
	−10	0	+ 1	0	+ 3	0	0	0	0	− 1	− 1	0	0	0	0	− 3	− 3
	+50	0	− 5	− 5	− 5	0	− 3	0	0	+ 2	+ 2	0	− 2	− 2	− 2	+ 4	+ 4
	−50	+1	+ 3	+ 3	+ 3	+1	+ 3	0	0	−11	−11	−16	−15	−15	−15	−20	*a*
Solar radiation	+10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum temp	+10	0	+ 3	+ 3	+ 3	0	+ 3	0	0	0	0	0	+ 3	+ 3	+ 6	0	0
	−10	0	− 4	− 4	− 4	0	− 4	0	0	0	0	0	− 3	− 3	− 8	− 2	− 4
	+50	0	+ 6	+ 6	+ 8	0	+ 7	*b*	*b*	− 8	−78	0	+ 8	+ 8	+16	0	+ 2
	−50	0	−65	−65	−77	0	−62	0	0	−56	−69	0	−62	*c*	*c*	+ 1	−12
Minimum temp	+10	0	+ 2	+ 2	+ 2	0	+ 2	0	0	0	0	0	+ 3	+ 3	+ 5	0	0
	−10	0	− 3	− 3	− 3	0	− 3	0	0	0	0	0	− 3	− 3	− 6	0	− 1
	+50	0	+ 6	+ 6	+ 8	0	+ 6	*b*	*b*	−77	−75	0	+ 7	+ 7	+13	0	+ 2
	−50	0	−27	−27	−33	0	−27	0	0	−21	−27	0	−27	−27	−61	−80	*a*
Photosynthetic day length	+10	0	− 4	− 4	− 4	0	− 4	0	0	0	0	0	− 4	− 4	− 4	0	0
	−10	0	+ 1	+ 1	+ 1	0	+ 1	0	0	0	0	0	+ 2	+ 2	+ 3	0	0
	+50	0	*a*	*c*	*c*	0	*a*	0	0	*c*	*c*	0	*a*	*c*	*c*	*c*	*c*
	−50	0	+ 2	+ 2	+ 2	0	+ 2	0	0	0	0	0	+ 3	+ 3	+ 4	0	0

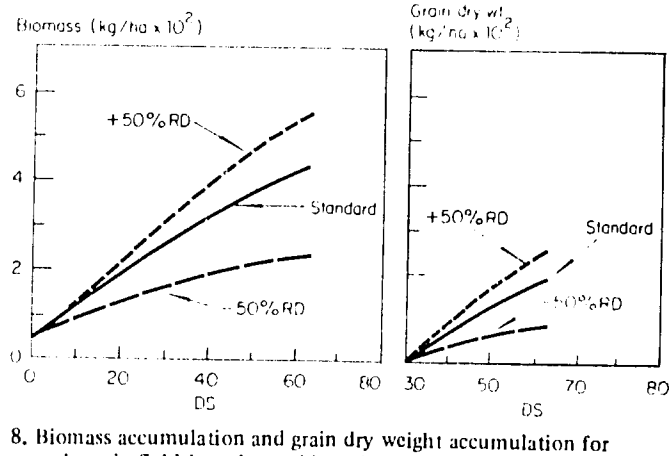
[a]Crop was planted but not harvested within the same crop year. [b]Crop was planted in this test, but not in the standard. [c]Crop was not planted in this test, but was in the standard.

crease in rainfall is caused by a 16-17 day planting delay for DSR and TPR crops (Table 7). Late planting did not affect DSR yield, but since TPR did not ripen until late December and early January, months which have low total and daily rainfall (Table 2), a 50% rainfall increase was not enough to offset drought stress.

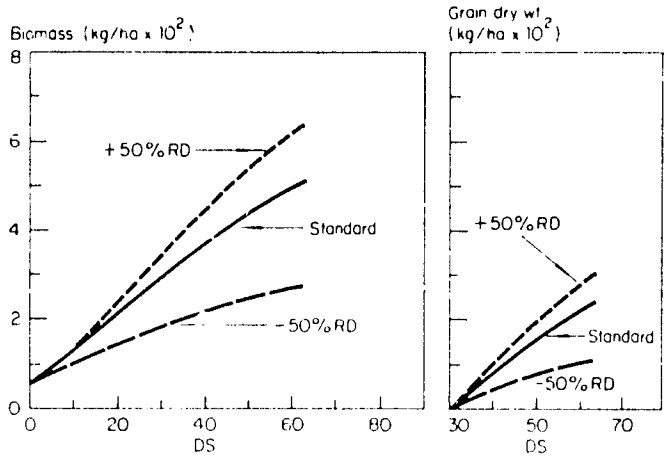
The effect of changing radiation level (RD) on mungbean development and grain weights is shown in Figures 8 and 9 for fields 1 and 5. As with rice, the more hydraulically favorable landscape position also favors the predicted growth rate in field 5 as compared to field 1.

The predicted changes in planting and harvesting date caused by changing climatic variables are given in Table 7 for fields 1, 3, and 5. Greater planting and harvesting changes are predicted for rainfall variations on lowland (field 5) than on upland (field 1). This would be expected, especially for increases in rainfall, because the lower field is affected by seepage and upward flow from the water table that the upper field does not receive. Changes in pan evaporation did not affect planting and harvesting dates as much as variations in rainfall, and solar radiation had no effect.

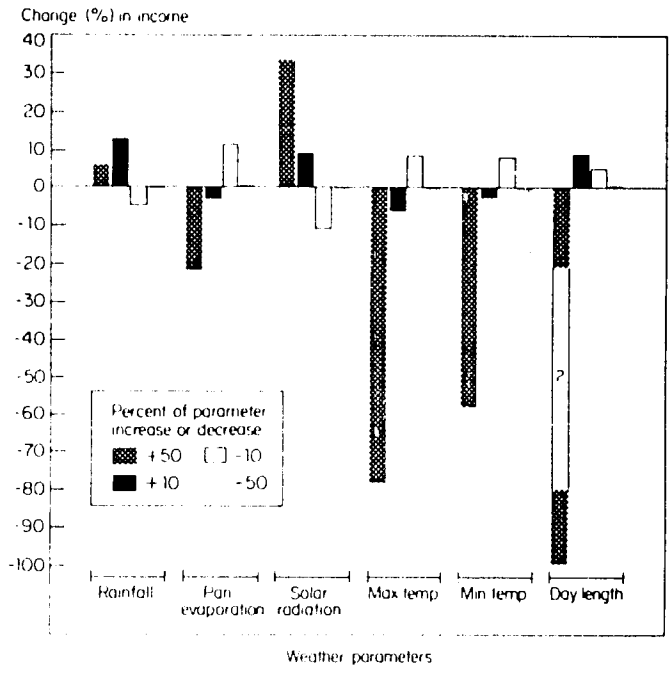
As with the yield predictions, varying maximum and minimum temperature affected the model more than changing other climate variables. In Table 7, as in Table 6, many exceptions are footnoted, especially in the temperature sections. Many times these are for crops that are planted in the test, such as TPR, and not in the standard situation. In this instance, the higher temperature caused the DSR crop to mature earlier, allowing time for the TPR crop that normally would not have been planted, and therefore affecting later crops in the sequence. For example, in field 2 a 10% increase in rainfall caused a TPR crop to be plant-



8. Biomass accumulation and grain dry weight accumulation for mungbean in field 1 as changed by solar radiation (RD). DS = days after seeding.



9. Biomass accumulation and grain dry weight accumulation for mungbean in field 5 as changed by solar radiation (RD). DS = days after seeding.



10. Change in gross income for the toposequence as a function of change in the weather parameter. For ? : s Figures 3 and 4.

ed. This delay put the mungbean crop in a different weather pattern with generally higher radiation, which encouraged larger yields. Apparently the standard rainfall was just below a critical amount necessary for a TPR crop in field 2, and a 10% increase pushed it past this amount (Angus 1979).

The effect of changing day length on predicted planting and harvest dates caused other problems (footnotes b and c in Table 6, footnotes a and c in Table 7). Increasing day length and spreading the total radiation over a longer period delayed DSR maturity and succeeding crops could not be planted. In Table 6, footnote b, the mungbean crop failed because late planting delayed maturity beyond 31 March, which was the simulation termination date.

By assigning 1978 commodity prices received by farm-

Table 8. Effect of changing weather variables on projected gross income as a % change from the standard.

Variable	% change of variable	Gross income as % change from standard					Toposequence average (%)
		Field 1	Field 2	Field 3	Field 4	Field 5	
Rainfall	+10	1.5	60.0[a]	5.6	1.8	0.9	12.4[a]
	−10	− 1.3	− 5.1	− 3.4	− 7.7	− 3.4	− 4.7
	+50	10.0	4.7	16.3	3.8	2.0	6.0
	−50	−19.0	−24.5	−45.3	−52.1[b]	−46.5[b]	−41.5[b]
Pan evaporation	+10	− 1.6	− 3.7	− 3.3	− 2.5	− 1.6	− 2.5
	−10	2.1	54.7[a]	6.0	1.9	1.4	11.7
	+50	−10.1	−17.4	− 8.2	−47.7	−11.7	−22.2
	−50	16.2	5.4	15.6	4.0	−13.8[b]	2.1[b]
Solar radiation	+10	7.0	9.2	10.1	9.2	9.0	9.1
	−10	− 8.0	−10.8	−11.7	−10.7	−10.5	−10.6
	+50	26.0	33.3	36.9	33.9	33.3	33.4
	−50	−52.0	−66.0	−66.8	−63.5	−63.4	−63.4
Maximum temperature	+10	−11.6	35.2[a]	−20.1	−15.3	−14.8	− 6.7[a]
	−10	6.0	11.1	12.2	6.4	8.6	8.8
	+50	−83.8	−71.9	−69.7[a]	−82.6	−82.8	−78.8[a]
	−50	−16.7	−13.8	−12.1	−45.2	−42.6	−31.0
Minimum temperature	+10	− 8.0	41.4[a]	−13.9	−11.2	−10.8	− 2.0[a]
	−10	5.5	9.2	10.3	7.2	7.2	7.9
	+50	−61.5	−44.0[a]	−45.3[a]	−65.3	−65.3	−57.9[a]
	−50	− 4.9	4.2	6.2	−36.5[b]	−27.8[b]	−17.1[b]
Photoperiod	+10	5.2	11.1	13.2	5.9	8.4	8.7
	−10	− 1.6	44.7[a]	− 4.3	− 4.1	− 3.8	4.7[a]
	+50	−100[b]	−100[b]	−100[b]	−100[b]	−100[b]	−100[b]
	−50	− 2.9	48.9[a]	− 7.4	− 6.2	− 5.8	3.7[a]

[a]One or more crops were planted and harvested than in the standard. [b]One or more crops were not harvested or planted compared to the standard.

ers in Iloilo to each crop in each field of the toposequence, Angus (pers. comm.) determined gross income per field for all of the toposequence year's simulation. Incomes for standard and test simulations, as percent decrease or increase, are compared in Table 8 and Figure 10. For some climatic variables, such as rainfall, all predicted changes were of the same sign for a given percent change in rainfall. For other parameters, such as maximum temperature, signs were different (Fig. 10). Thus, part of the toposequence might contribute a positive gross income while others reduce income. However, as shown in Table 5, the lower fields had higher predicted yields; therefore, a given percent change in gross income equals a greater income difference than for the upper fields in the sequence.

Soil variables

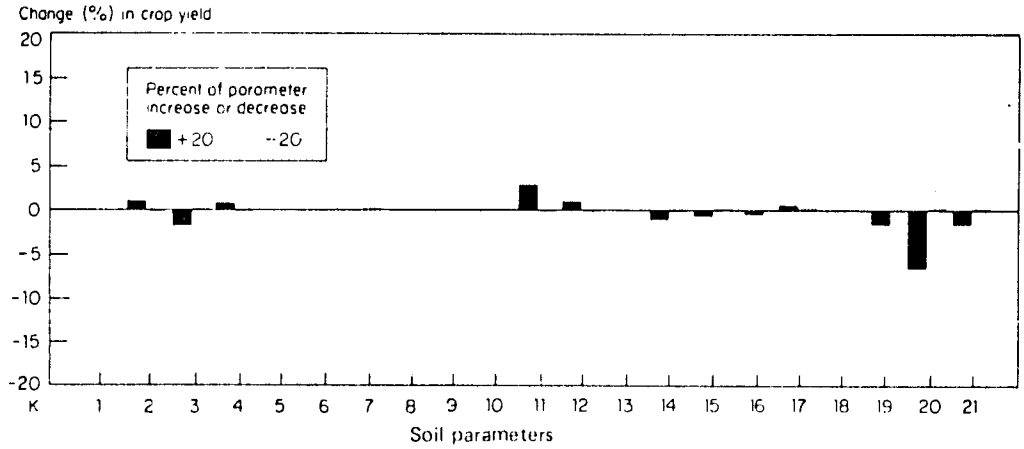
The predicted percent changes in grain yields as a function of change in the soil variables are shown in Table 9, those for field 5 are in Fig. 11. Usually, the model was not as sensitive to changes in soil variables as to changes in climate variables (compare Figures 2 and 11). This also has been true for other models (Whisler et al 1979a, b; Whisler 1983a).

The hydraulic parameters of K = 2, 3, 4, 6, 14, 17, 20, and 21, when changed from the standard amounts allowed a TPR planting in fields 2 and 3 that usually could not happen. Table 10 shows that changing soil variables altered planting and harvesting time. The TPR crop delayed the mungbean planting, and the mungbean yields were generally

Table 9. Effect of changing soil variables on simulated crop yield as % change from the standard.

K	% change of variable	Crop yield as % change from the standard													
		Field 1		Field 2			Field 3			Field 4			Field 5		
		DSR	Mung	DSR	TPR	Mung	DSR	TPR	Mung	DSR	TPR	Mung	DSR	TPR	Mung
1	+20	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	-0.9
	-20	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2	+20	9.7	0.2	3.0	2512[a]	23.4	1.5	0.0	0.0	3.6	-0.1	-100[b]	1.2	0.0	0.5
	-20	-70.8	-0.2	-13.7	0.0	0.0	-12.4	0.0	0.3	-15.0	-31.3	0.0	-13.4	0.4	-0.9
3	+20	3.0	0.0	-0.7	0.0	0.0	-0.4	0.0	0.2	-0.7	-0.2	0.0	-1.8	0.0	-0.4
	-20	2.1	0.0	1.1	2504[a]	23.4	2.9	0.0	0.0	2.0	0.0	0.0	1.3	0.0	0.0
4	+20	0.0	0.0	-0.3	0.0	0.0	1.0	0.0	0.2	-0.1	0.0	0.0	0.7	0.0	-0.4
	-20	0.0	0.0	0.3	2212[a]	23.4	0.0	0.0	0.0	-0.1	0.0	0.0	-0.5	0.0	0.5
5	+20	0.0	0.0	0.0	0.0	0.0	-0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	-1.3
	-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.5
6	+20	-0.4	0.0	0.0	0.0	0.0	-0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.5
	-20	2.8	0.0	0.0	2212[a]	-2.4	6.8	0.0	0.0	0.0	0.0	-12.8	0.0	0.0	-7.0
7	+20	-0.3	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-1.1	0.0	0.0	-0.9
	-20	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.2	0.0	0.0	0.0	0.6	0.0	0.5
8	+20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	+20	-0.2	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	+20	-0.2	0.0	0.0	0.0	0.0	-0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	-0.9
	-20	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.5
11	+20	11.0	0.0	3.1	0.0	0.0	2.2	0.0	0.0	2.6	0.4	0.0	2.8	0.4	0.0
	-20	-11.8	0.0	-3.7	0.0	0.0	-2.9	0.0	0.0	-3.6	-0.4	0.0	-3.7	-0.4	0.0
12	+20	5.6	0.0	1.0	0.0	0.0	0.9	0.0	0.0	0.6	-0.7	0.0	0.7	-0.7	0.0
	-20	-7.2	0.0	-1.6	0.0	0.0	-1.4	0.0	0.0	-1.4	0.9	0.0	-1.5	0.9	0.0
13	+20	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	+20	-2.2	-0.2	0.1	2213[a]	23.4	1.2	0.0	0.0	0.1	0.1	-0.6	-0.4	-0.8	0.0
	-20	2.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	-0.2	0.0	0.0
15	+20	-0.3	-0.2	-0.6	0.0	0.0	-0.5	0.0	0.0	-0.6	0.0	0.0	-0.5	0.0	0.0
	-20	0.5	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.0	0.6	0.0	0.0
16	+20	-1.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
	-20	0.4	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
17	+20	0.3	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-20	-3.8	1.0	1.8	2565[a]	15.8	-2.1	2585[a]	14.7	2.0	2.4	-6.1	1.8	2.6	0.0
18	+20	0.1	0.0	0.5	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
	-20	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	+20	0.8	0.0	0.1	0.0	0.0	7.6	0.0	0.0	0.2	0.0	0.0	1.5	0.0	0.0
	-20	-0.4	0.0	0.0	0.0	0.0	-0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
20	+20	-22.0	0.0	-9.0	0.0	0.0	-6.8	0.0	0.3	-9.0	0.0	0.0	-6.9	0.3	0.0
	-20	8.1	-0.7	4.0	2208[a]	23.4	4.7	0.0	0.0	4.2	-0.1	0.0	2.9	0.1	-0.4
21	+20	-3.0	0.0	-0.7	0.0	0.0	-0.4	0.0	0.2	-0.7	-0.2	0.0	-1.8	0.0	0.0
	-20	2.1	0.0	1.1	2211[a]	23.4	2.9	0.0	0.0	2.0	0.0	0.0	1.3	0.0	0.0

[a]Crop was planted in this test, but not in the standard. [b]Crop was not planted in this test, but was in the standard.



11. Crop yield for dry seeded rice in field 5 as a function of change of the soil parameter.

Table 10. Effect of changing soil variables on estimated planting (P) and harvesting (H) dates as the number of days of difference from the standard.

K	% change of variable	No. of days of difference from standard															
		Field 1				Field 3						Field 5					
		DSR		Mung		DSR		TPR		Mung		DSR		TPR		Mung	
		P	H	P	H	P	H	P	H	P	H	P	H	P	H	P	H
1	+20	0	0	0	0	0	0	0	0	+ 2	+ 2	0	0	0	0	+2	+2
	-20	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	0	0	0
2	+20	0	+ 1	+1	+1	0	0	0	0	0	0	0	0	0	0	−1	−1
	−20	0	− 1	−1	−1	− 3	− 4	0	0	+ 2	+ 2	0	− 1	− 1	− 1	+2	+2
3	+20	0	0	0	0	0	0	0	0	+ 1	+ 1	0	0	0	0	+1	+1
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	+20	0	0	0	0	0	0	0	0	+ 1	+ 1	0	0	0	0	+1	+1
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1	−1
5	+20	0	0	0	0	0	0	0	0	+ 2	+ 2	0	0	0	0	+3	+3
	−20	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	0	−1	−1
6	+20	0	0	0	0	0	0	0	0	+ 2	+ 2	0	0	0	0	−1	−1
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+3	+3
7	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+2	+2
	−20	0	0	0	0	0	+ 1	0	0	+ 1	+ 1	0	0	0	0	−1	−1
8	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	+20	0	0	0	0	0	0	0	0	+ 2	+ 2	0	0	0	0	+2	+2
	−20	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	0	−1	−1
11	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	+20	+1	− 1	−1	−1	+ 1	0	0	0	0	0	− 3	− 3	− 3	− 3	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	+20	0	− 1	−1	−1	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	+20	−1	− 1	−1	−1	0	0	0	0	0	0	0	0	0	0	0	0
	−20	+1	+12	+7	+7	+11	+11	*b*	*b*	−84	−84	+11	+11	+11	+11	0	0
18	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	+20	0	0	0	0	0	+ 1	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	+ 2	+ 2	0	0	0	0	0	0
20	+20	0	0	0	0	0	+ 1	0	0	+ 2	+ 2	0	0	0	0	0	0
	−20	−1	− 4	−4	−4	0	− 2	0	0	0	0	0	+ 1	+ 1	+ 1	+1	+1
21	+20	0	0	0	0	0	0	0	0	+ 1	+ 1	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a]Crop was not planted in this test but was in the standard. [b]Crop was planted in this test but not in the standard.

Table 11. Effect of changing soil variables on projected gross income as a % change from the standard.

K	% change of variable	Gross income as % change from standard					Topo-sequence average (%)
		Field 1	Field 2	Field 3	Field 4	Field 5	
1	+20	-0.1	0.0	0.1	0.0	-0.1	0.0
	-20	0.1	0.0	-0.1	0.0	0.0	0.0
2	+20	6.0	60.3[a]	1.2	1.9	0.7	12.1[a]
	-20	-43.4	-11.0	-9.7	-33.2[b]	-7.0	-18.9[b]
3	+20	-1.8	-0.5	-0.2	-0.5	-1.0	-0.7
	-20	1.3	58.6[a]	2.3	1.0	0.7	-11.3[a]
4	+20	0.0	-0.3	0.8	-0.1	0.3	0.1
	-20	0.0	51.8[a]	0.0	0.0	-0.2	9.0
5	+20	0.0	0.0	-0.4	0.0	-0.2	-0.1
	-20	0.0	0.0	0.0	0.0	0.1	0.0
6	+20	-0.2	0.0	-0.5	0.0	0.1	-0.1
	-20	1.7	46.4[a]	5.3	-1.9	-1.0	8.3
7	+20	-0.2	0.0	-0.1	-0.2	-0.1	-0.1
	-20	0.0	0.0	3.5	0.0	0.4	0.7
8	+20	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.0	0.0	0.0	0.0	0.0	0.0
9	+20	-0.1	0.0	-0.1	0.0	0.0	0.0
	-20	0.1	0.0	0.2	0.0	0.0	0.0
10	+20	-0.1	0.0	0.0	0.0	-0.1	0.0
	-20	0.0	0.0	0.0	0.0	0.1	0.0
11	+20	6.8	2.5	1.7	1.5	1.6	2.2
	-20	-7.2	-3.0	-2.2	-2.0	-2.1	-2.7
12	+20	3.4	0.8	0.7	0.1	0.2	0.6
	-20	-4.4	-1.3	-1.1	-0.4	-0.5	-1.1
13	+20	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.1	0.0	0.0	0.0	0.0	0.0
14	+20	-1.4	51.6[a]	0.9	0.0	-0.5	9.0[a]
	-20	1.3	0.1	0.4	0.2	-0.1	0.2
15	+20	-0.3	-0.5	-0.4	-0.3	-0.3	-0.3
	-20	0.3	0.3	0.1	0.2	0.3	0.3
16	+20	-0.7	0.0	0.0	0.0	-0.1	-0.1
	-20	0.2	-0.1	0.0	-0.1	0.0	0.0
17	+20	0.1	0.0	0.0	0.0	0.0	0.0
	-20	-2.0	58.9[a]	61.3[a]	0.9	1.8	20.8[a]
18	+20	0.1	0.4	0.2	0.3	0.0	0.2
	-20	0.0	0.0	0.0	0.0	0.0	0.0
19	+20	0.5	0.1	6.0	0.1	0.8	1.3
	-20	-0.3	0.0	-0.2	0.0	0.0	-0.1
20	+20	-13.5	-7.3	-5.2	-8.4	-3.5	-6.7
	-20	4.7	54.7[a]	3.7	2.1	1.5	11.7[a]
21	+20	-1.8	-0.5	-0.2	-0.5	-0.9	-0.7
	-20	1.3	52.4[a]	2.3	1.0	0.7	10.2[a]

[a]Crop was planted in this test but not in the standard. [b]Crop was not planted in this test but was in the standard.

increased because of higher radiation at the later dates. These results indicate the soil and weather parameters had a combined effect. The model generally is most sensitive to changes in hydraulic parameters, especially 2, 20, and 21. Among the nitrogen transformation parameters, 11 and 12 produced the biggest model changes.

The effects of changing soil parameters on predicted gross income are shown in Table 11 and Figure 12. As with the weather parameters, changing the soil parameter sometimes caused a monotonic change in all fields, that is, all fields showed either a positive or negative change such as for K = 2. In other cases, such as for K = 4, the predicted changes had mixed signs.

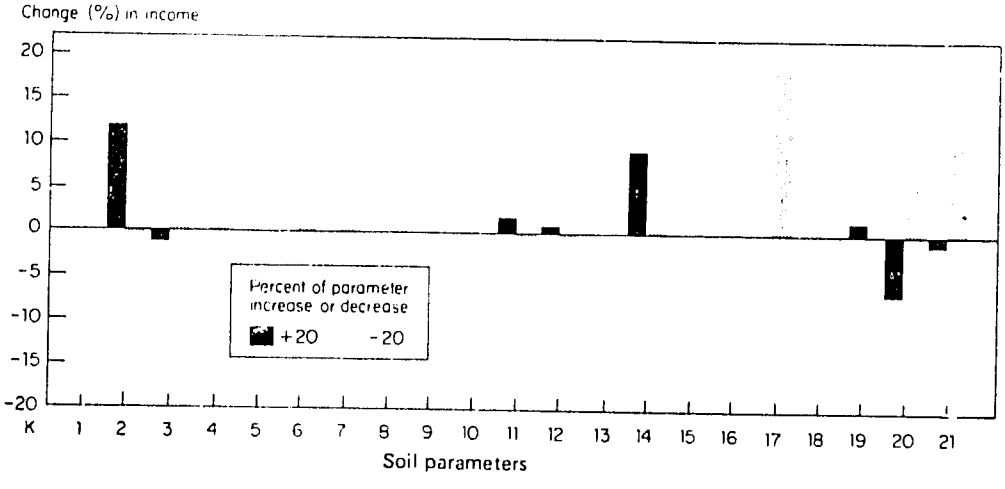
Some soil variables did not affect IRRIMOD predictions in these tests, since these were conducted for a specific data set of climatic, crop, and management variables. At other levels, the model might be sensitive to these soil variables. A more rigorous test would be to conduct a few well-chosen validation tests of all the model subroutines before any variables could be labeled ineffective and dropped from the model. They all are used in the model as a zero value, for each variable was tested.

Alternative interpretations

In addition to being a sensitivity test for IRRIMOD the results that have been described are useful to meteorologists and soil physicists. They can help answer questions such as: "What difference does it make if my instrument or procedure is off by ±10%? ±20%?, etc.?" This analysis shows that an instrument that always measures high in minimum temperature would generally cause the model to underestimate yield. Likewise, a procedure that gives too small a value in percolation rate (K=3) could cause the model to overestimate yield by a noticeable magnitude. Therefore, this sensitivity exercise is of both academic and practical interest.

Combinations of changes

As different climatic patterns are examined, the variables change simultaneously and not individually. Several com-



12. Change in gross income for the toposequence as a function of change in the soil parameter.

binations were examined to see what simulation differences would be generated by keeping the same rainfall data. A more northern latitude was simulated by increasing pan evaporation 6%, radiation 11%, maximum temperature 4%, minimum temperature 1%, and day length 5%. A more southern latitude was simulated by decreasing pan evaporation 14%, radiation 13%, and maximum temperature 8%; increasing minimum temperature 4%; and decreasing day length 5%. These changes were based on long-term weather record comparisons of Cabanatuan, Philippines (14°N) (similar to IRRI) with Parwanipur in Nepal (28°N) and Singapore (1°N). The results are given in Table 12 in terms of percentage change from the standard simulations.

IRRIMOD predicted that moving these soils and crops to a more northern latitude would generally increase all yields, even though rainfall is not changed. Predictions indicated some rice crops would have delayed maturity and some mungbean crops would be planted and harvested earlier. Each field of the toposequence was predicted to give a higher gross income, based on higher yields.

Predictions for moving to a more equatorial climate were not as uniform. Most rice and mungbean crops would have decreased yield and some would have delayed maturity. In field 2, however, a predicted TPR rice crop increased overall yield and income, which caused an overall slight increase in gross income for the entire toposequence to be predicted. All the other fields had lower yield and decreased gross income.

Table 12. Effects of changing latitudes on model predictions.

Latitude	Field	Crop	% change from standard simulations			
			Yield (% change)	Planting (days)	Harvesting (days)	Gross income
Higher	1	DSR	5.2	0	−1	3.9
		Mung	1.9	− 1	−1	
	2	DSR	7.0	0	−1	6.2
		Mung	3.0	0	0	
	3	DSR	8.0	0	−1	6.8
		Mung	2.5	+ 2	+2	
	4	DSR	6.2	0	0	7.2
		TPR	9.7	0	0	
		Mung	4.8	0	0	
	5	DSR	6.5	0	0	7.1
		TPR	9.6	0	0	
		Mung	3.5	+ 2	+2	
	Overall					6.6
Lower	1	DSR	− 5.7	0	0	− 6.4
		Mung	− 7.5	0	0	
	2	DSR	− 9.4	0	0	43.1
		TPR	2238[a]	a	a	
		Mung	16.2	−88	−90	
	3	DSR	− 6.1	0	0	− 6.7
		Mung	− 8.6	− 3	−3	
	4	DSR	− 9.6	0	0	− 9.4
		TPR	−10.6	0	−2	
		Mung	− 5.9	− 2	−3	
	5	DSR	−11.0	− 3	−3	−10.2
		TPR	−11.3	− 3	−5	
		Mung	− 4.8	− 3	−4	
	Overall					0.3

[a]Crop planted in this test but not in the standard.

Table 13. Effects of soil compaction on model predictions.

Soil compaction	Field	Crop	% change from standard simulation			
			Yield (% change)	Planting (days)	Harvesting (days)	Gross income
Increased	1	DSR[a]	100	–	–	−96.8[a]
		Mung	− 91.9	−36	−35	
	2	DSR	− 20.3	+ 6	0	41.1[b]
		TPR[b]	2489	b	b	
		Mung	23.4	−86	−87	
	3	DSR[a]	−100	–	–	−98.7[a]
		Mung	− 93.8	−93	−94	
	4	DSR[a]	−100	–	–	−88.3[a]
		TPR[a]	−100	–	–	–
		Mung	− 22.0	+55	+56	
	5	DSR	− 10.3	+10	+10	− 3.4
		TPR	3.4	+10	+10	
		Mung	5.3	−14	−14	
	Overall					−43.5
Decreased	1	DSR	155.4	−19	−19	93.3
		Mung	− 4.9	−15	−15	
	2	DSR	8.9	0	0	7.5
		Mung	0.0	0	0	
	3	DSR	36.7	−19	−19	27.9
		Mung	− 4.1	−23	−23	
	4	DSR	7.4	0	0	−18.0[c]
		TPR	− 20.5	−28	−31	
		Mung	−100[c]	−74	c	
	5	DSR	0.7	0	0	− 0.1
		TPR	0.4	0	0	
		Mung	− 1.9	+ 4	+ 4	
	Overall					9.2

[a]Crop not planted in this test but was in the standard. [b]Crop planted in this test but not in the standard. [c]Crop planted in the test but not harvested.

As soil aggregation increases, total porosity, saturated water content, and slope of the moisture characteristic curve may increase as well as permeability (Hillel 1980). The reverse occurs with compaction or decreased aggregation. Compaction also slows the nitrogen transformation rates (Whisler et al 1965). Increased aggregation (decreased compaction) was simulated by increasing K=2, 6, 11, 12, and 17 by 20% and K=3, 4, 9, 15, and 21 by 50%, and decreasing K=13, 14, and 20 by 20%. Reverse algebraic signs were used to indicate decreased aggregation (increased compaction). Results are shown in Table 13.

In general, increasing compaction reduced predicted yields and gross income. Field 2 was an exception because the TPR crop that could be planted increased total yield and gross income. Rice crops were not predicted to be planted in fields 1, 3, and 4, and that severely reduced gross income generation for the three fields and for the overall toposequence. When compaction was decreased below the standard, the overall effect was to predict higher yields and gross income. There were, however, notable exceptions for mungbean and in field 4 TPR. These effects generally were due to predicted delayed planting because of the higher

Table 14. Effects of soil texture on model predictions.

Soil texture	Field	Crop	% change from standard			
			Yield (% change)	Planting (days)	Harvesting (days)	Gross income
Increased sand	1	DSR	90.4	+11	+10	55.7
		Mung	1.0	+ 7	+ 7	
	2	DSR	− 0.1	+11	+10	54.4
		TPR[a]	2416	[a]	[a]	
		Mung	16.4	−76	−76	
	3	DSR	17.9	+11	+12	14.1
		Mung	0.3	+ 2	+ 2	
	4	DSR	− 0.8	+11	+11	−1.5
		TPR	− 0.7	+11	+10	
		Mung	− 5.6	+10	+11	
	5	DSR	3.3	+11	+11	1.4
		TPR	2.6	+11	+11	
		Mung	− 7.4	+14	+15	
	Overall					16.9
Increased clay	1	DSR	161.0	0	0	96.8
		Mung	0.3	+ 2	+ 2	
	2	DSR	9.9	0	+ 1	64.6
		TPR[a]	2522	[a]	[a]	
		Mung	16.4	−85	−86	
	3	DSR	24.9	0	+ 1	19.5
		Mung	− 0.1	−59	−59	
	4	DSR	9.0	0	+ 1	4.6
		TPR	0.0	+ 1	+ 1	
		Mung	− 0.6	+ 1	+ 1	
	5	DSR	6.2	0	+ 1	3.3
		TPR	0.0	+ 1	+ 1	
		Mung	0.5	− 1	− 1	
	Overall					25.7

[a]Crop planted in this test but not in the standard.

permeability and water storage requirements. This last example would seem to point to increased tillage of the upper landscape and reduced tillage of the lower.

As clay content increases, total porosity and water holding capacity increase, but permeability decreases (Hillel 1980). The reverse happens as clay content decreases and sand content increases. Increased sand content was simulated by increasing K = 3, 4, 9, 10, 15, 16, and 21 by 50% and decreasing K = 2, 6, 7, 14, 17, and 20 by 20%. The reverse was done to simulate increased clay content. The results of these simulations are given in Table 14 as a percent change from the standard.

IRRIMOD predicted that most yields would increase with increased sand content, as would most field incomes and overall income. Field 4 was an exception. Its yields and incomes were predicted to decrease. Field 2 was predicted to have a TPR rice crop which increased production and overall income. This response to increased sand content is similar to responses using other models (Whisler 1983a, Whisler et al 1979b).

As clay content increased above standard, most yields and income also were predicted to increase. Field 2 again had a TPR rice crop. Fields 3 and 4 mungbean crops, however, were predicted to have decreased yields. The response to increased clay is unexpected (Whisler 1983a) and difficult to understand.

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