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SENSITIVITY TESTS OF THE CROP AND MANAGEMENT VARIABLES IN IRRIMOD

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ABSTRACT

IRRIMOD, the multiple field, multiple crop toposequence, rice-based model developed by Angus (1979) and Angus and Zandstra (1980), was tested for sensitivity to its crop and management input parameters. The model includes parameters for equations that describe plant growth for direct dry- and wet-seeded rice, transplanted rice, ratoon rice, mungbean, maize, and sorghum. These equations are called Gompertz functions and have a normal S shape when plotted. The model contains exponential equations for each crop with specified parameters that relate crop development rate to temperature, photoperiod, solar radiation, and nitrogen stress. It also has crop parameters that are estimates of biomass at certain development stages. The management parameters are for spillway or bund height, weight and development stage of plants at transplanting, seeding rate, timing and amount of nitrogen fertilizer, turnaround period between crops, and time of year when a transplanted rice crop will no longer be considered.

IRRIMOD was more sensitive to crop parameters than to management parameters. It was most sensitive to the growth curve parameters initial growth rate and inflection approaching maturity and the optimum temperature for growth parameter. If IRRIMOD were used as a breeding program tool, it would indicate that breeding lines with an initial high dry matter accumulation rate and a higher fraction of dry matter accumulation after anthesis would be most desirable. IRRIMOD was most sensitive to the management parameter of initial biomass at planting, which can be interpreted as plant population per hectare.

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SENSITIVITY TESTS OF THE CROP AND MANAGEMENT VARIABLES IN IRRIMOD

The multiple field, multiple crop, rice-based simulation model IRRIMOD was developed and described by Angus (1979) and Angus and Zandstra (1980). It is a toposequence model at what the author describes as "the agronomic level" of detail, in contrast to "physiological" models. The model includes parameters for equations that describe plant growth for direct dry- and wet-seeded rice, transplanted rice, ratoon rice, mungbean, maize, and sorghum. These equations are called Gompertz functions and have a normal S shape when plotted as a function of time (Angus 1979) (Fig. 10). The model contains exponential equations for each crop with specified parameters that relate crop development rate to temperature, photoperiod, solar radiation, and nitrogen stress (Angus 1979). It also has parameters that are estimates of biomass at certain development stages. These are called crop parameters and their descriptions and units are given in Table 1.

IRRIMOD also requires values for management or farmer-controlled parameters such as spillway or bund height, plant size and age at transplanting time, seeding rate, timing and amount of nitrogen fertilizer application, turnaround time between crops, and time of year when a transplanted rice crop will no longer be considered. Units and descriptions of these management parameters are given in Table 2.

Both Angus publications include comparisons of model output to independently taken field data or validation tests. However, not every part of the model has been validated. The model's response to changes in input parameters should also be tested. Sensitivity testing or analyses such as these were performed by Whisler (1984) for the environmental variables of IRRIMOD. This report extends the analyses to IRRIMOD crop and management variables and gives some of the calculated biomass production, yields, and gross returns.

Table 1. Crop parameters and units used in IRRIMOD.

K	Parameter	Unit
1	Gompertz constant 1, highest biomass achievable	t ha^{-1}
2	Gompertz constant 2, relative growth rate at time 0	*
3	Gompertz constant 3, inflection approaching maturity	*
4	Base temperature for development and growth	^{o}C
5	Peak rate of preanthesis development	d^{-1}
6	Curvature of exponential equation for development	*
7	Constant for photoperiod prior to anthesis	*
8	Critical photoperiod for preanthesis development	h
9	Proportion of development executed prior to anthesis	*
10	Peak rate of postanthesis development	d^{-1}
11	Optimum temperature for growth	^{o}C
12	Curvature of exponential equation for response	*
13	Radiation required for most rapid growth	cal cm^{-2} d^{-1}
14	Curvature of exponential equation for nitrogen stress	*
15	Proportion of nitrogen in biomass at ten development stages for crop supplied with luxury inputs	*
16	Proportion of biomass at anthesis translocated to grain – low N stress	*
17	Proportion of biomass at anthesis translocated to grain – heavy stress	*
18	Biomass at full canopy cover	kg ha^{-1}
19	Biomass at completion of second stage evaporation	kg ha^{-1}

*Dimensionless.

METHOD

Two versions of the model were prepared. In the first, crop parameters could be changed independently; in the second management relationship parameters could be changed independently. In any given test a percentage change of a particular variable was made with all others held constant. For example, the percolation rate of each field could be changed while maintaining constant water depth. The magnitude of the variable could be increased or decreased by changing the sign of the percentage.

Tests were made by changing the crop or management variable by 20%, a value that was chosen because it would normally be large enough to measure for measurable parameters. If the model is sensitive to a particular variable, a 20% change should cause a significant response. Standard

Table 2. Management parameters and units used in IRRIMOD.

M	Parameter	Unit
1	Starting value of biomass	kg ha^{-1}
2	Proportion of crop development completed at planting	*
3	Turnaround period (TAP) between 1st and 2d crop (or 2d and 3d)	day
4	Total 1st N application	kg N ha^{-1}
5	Crop age after planting at 1st N application	day
6	Total 2d N application	kg N ha^{-1}
7	Crop age after planting at 2d N application	day
8	Spillway (bund) height above field level	mm
9	Date after which 2d rice crop was not considered (days after 1 Apr)	day

*Dimensionless.

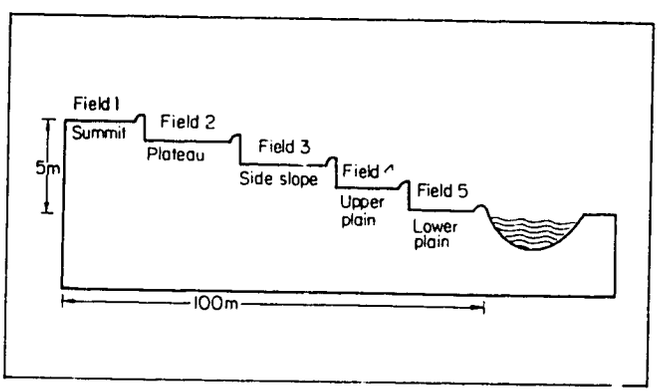
Table 3. Crop parameters for various potential crops used in IRRIMOD. (See Table 1 for units and description.)

K	IR36 TPR	IR36 WSR	BE3 TPR	IR36 DSR	IR36 ratoon	Sorghum	Mungbean	Maize
1	11.0	11.0	11.0	11.0	2.0	6.0	4.0	12.0
2	.130	.130	.130	.130	.130	.130	.130	.130
3	.025	.025	.025	.025	.025	.025	.025	.025
4	15.0	15.0	15.0	15.0	15.0	10.0	10.0	10.0
5	.015	.015	.014	.014	.025	.018	.033	.018
6	.20	.20	.20	.20	.20	.20	.20	.20
7	.70	.70	.70	.70	.70	.70	.70	.70
8	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
9	.700	.70	70	.700	.610	.660	.600	.600
10	.040	.040	.040	.040	.40	.033	.033	.025
11	27.0	27.0	27.0	27.0	27.0	27.0	24.0	24.0
12	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
13	700	700	700	700	700	700	700	700
14	4.20	4.20	4.20	4.20	4.20	3.50	3.50	3.50
15	.040	.040	.040	.040	.040	.040	.001	.040
	.050	.050	.050	.050	.050	.050	.001	.050
	.050	.050	.050	.050	.050	.050	.001	.050
	.040	.040	.040	.040	.040	.040	.001	.040
	.035	.035	.035	.035	.035	.035	.001	.035
	.030	.030	.030	.030	.030	.030	.001	.030
	.025	.025	.025	.025	.025	.025	.001	.025
	.020	.020	.020	.020	.020	.020	.001	.020
	.015	.015	.015	.015	.015	.015	.001	.015
	.010	.010	.010	.010	.010	.010	.010	.010
16	.100	.100	.100	.100	.100	.050	.050	.050
17	.150	.150	.150	.150	.150	.200	.200	.200
18	1000	1000	1000	1000	1000	1000	1000	1000
19	200	200	200	200	200	200	200	200

Table 4. Standard values of management variables used in IRRIMOD. (See Table 2 for units and description.)

M	Crop 1	Crop 2	Crop 3
1	100	440	50
2	0.0	0.15	0.0
3	10	10	1
4	20	20	10
5	2	2	1
6	20	20	0.0
7	30	30	0.0

	Field 1	Field 2	Field 3	Field 4	Field 5
8	1.0	100	100	100	100
9	170	190	180	220	240



1. Schematic diagram of toposequence used in IRRIMOD.

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

	Yield (kg ha^{-1})	Gross income (₱ ha^{-1})	Planting (day-mo)	Harvest (day-mo)
Field 1				
DSR	1494		1 - 6	23 - 9
Mung	189		24 - 9	27 - 11
		2441		
Field 2				
DSR	3788		1 - 6	21 - 9
Mung	185		7 - 10	10 - 12
		4714		
Field 3				
DSR	3387		1 - 6	22 - 9
Mung	188		29 - 9	2 - 12
		4326		
Field 4				
DSR	3935		1 - 6	21 - 9
TPR	2531		1 - 10	31 - 12
Mung	228		1 - 1	6 - 3
		7607		
Field 5				
DSR	4030		1 - 6	21 - 9
TPR	2530		1 - 10	31 - 12
Mung	235		7 - 1	12 - 3
		7737		

crop parameter values are given in Table 3, and management parameter values are listed in Table 4.

The crop growing season begins in April in eastern Philippines and progresses steadily westward (Zandstra et al 1980). IRRIMOD begins 1 April and calculates the soil water balance for each field in the toposequence. (A maximum of 5 fields are allowed [Fig. 1]). When the water balance is adequate, the first dry-seeded crop is planted, harvested, and subsequent specified crops are planted and harvested. (Usually a maximum of 3 crops are grown in one season.) Note the dimensions in Figure 1. In field 1, the depth of the water table is 5 m. In field 5 it is only 1 m. Other climate and soil variables are given in Whisler (1984) and were not varied during these analyses.

RESULTS AND DISCUSSION

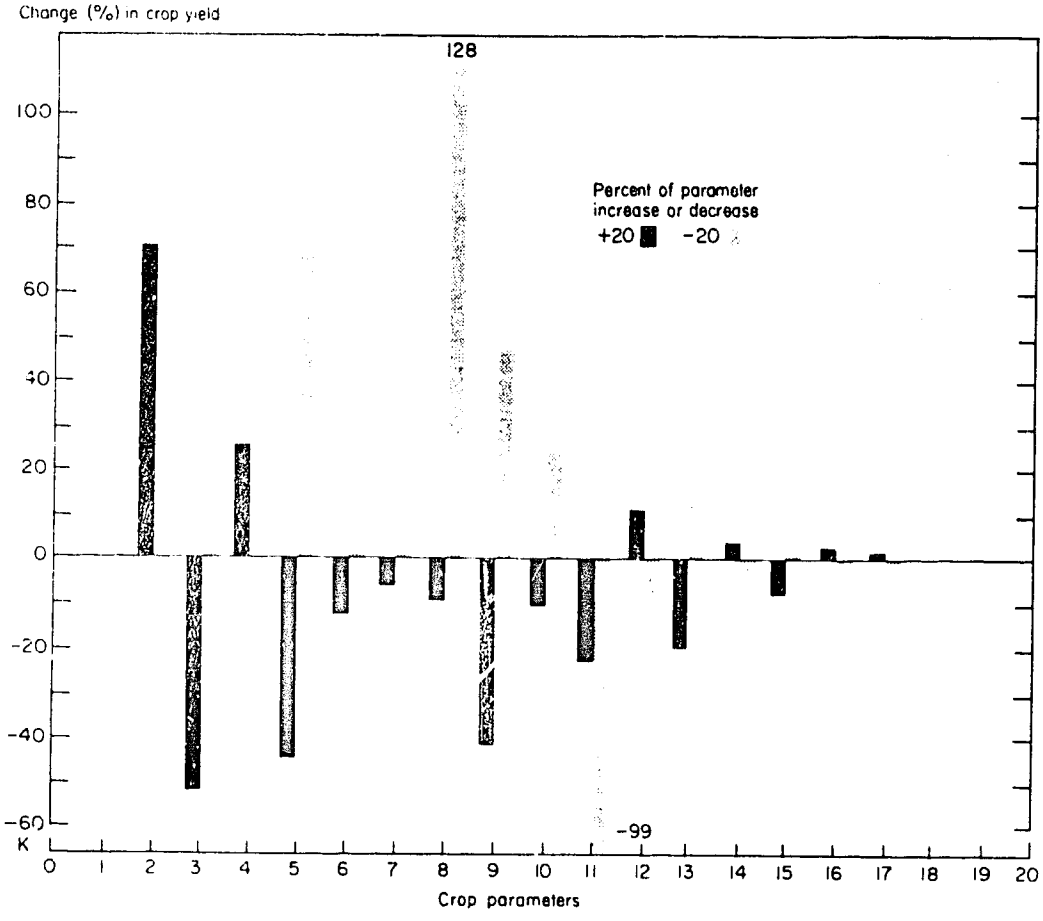
IRRIMOD calculates several measurable soil and crop quantities such as aboveground biomass, grain weight, crop nitrogen accumulation, soil water content, soil ammonium and nitrate nitrogen content, planting and harvesting date, and gross income per field. Only a few of these quantities will be discussed as indicators of the model's sensitivity.

Because IRRIMOD is incompletely validated, many results will be shown as % changes from the standard simulation. (The standard simulation is 0% change in any variable.) Table 5 gives some of the results of the standard simulation. The cropping sequence for each field was dry-seeded rice (DSR), transplanted rice (TPR), followed by mungbean (mung) if there was sufficient soil moisture. IR36 was used for calibration in these analyses. Fields were not of the same size nor did they have the same soil properties (Angus and Zandstra 1980, Whisler 1984). DSR and mung yields generally increase from fields 1 to 5, and fields 4 and 5 had a TPR crop, which caused the lower fields in the toposequence to have a higher gross income than the upper fields. DSR also matured earlier in the lower fields because of a better moisture balance. Mung yield in lower fields was

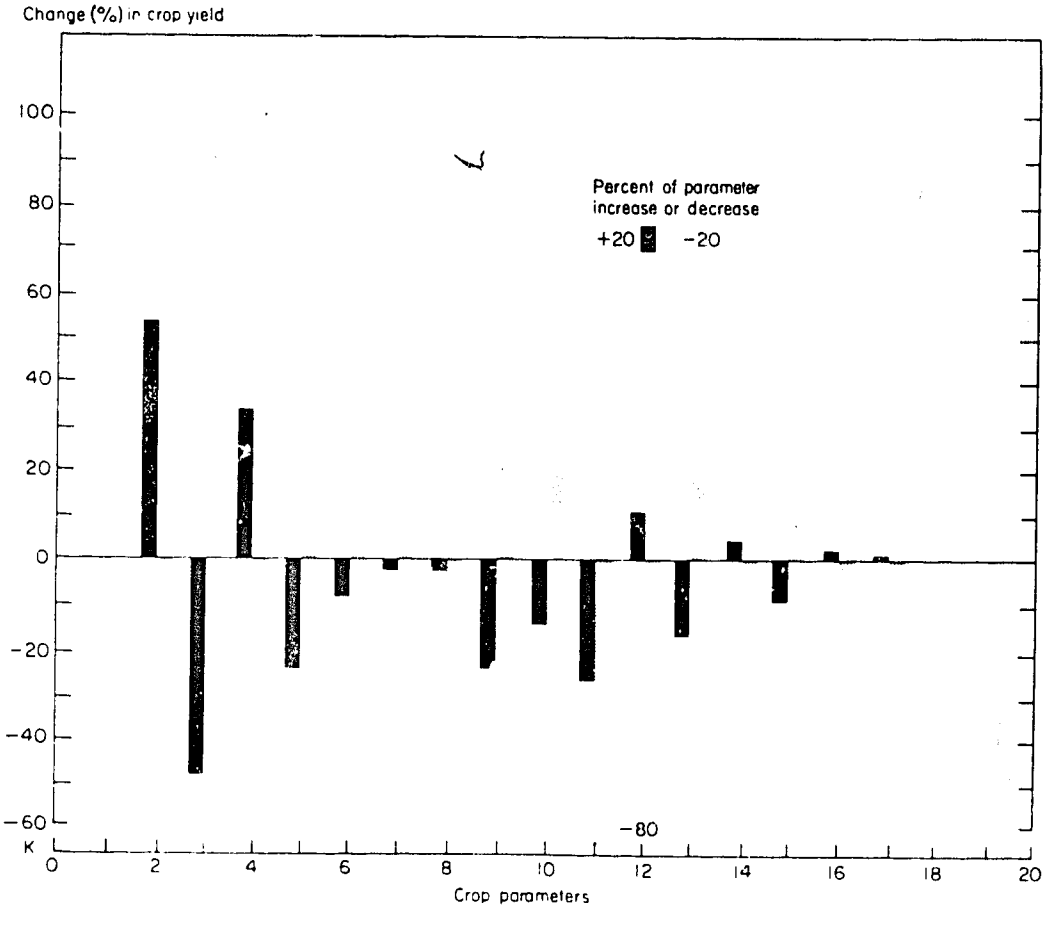
Table 6. Effect of changing crop variables on simulated crop yield as a % change from the standard.

K	% 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
1	+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
2	+20	44.6	69.9	72.0	0.0	69.4	85.2	0.0	69.7	78.2	53.9	74.5	76.5	53.9	75.4
	−20	−41.0	−43.0	−58.5	0.0	42.8	60.7	0.0	−42.9	−60.2	−43.0	−44.7	−60.0	−43.0	−45.0
3	+20	−42.6	−43.1	−51.7	0.0	42.9	54.4	0.0	43.0	−53.0	−47.8	−45.1	−52.7	−47.8	−45.3
	−20	75.4	92.9	100.6	0.0	91.9	115.6	0.0	92.5	106.4	94.9	100.6	104.8	94.8	101.4
4	+20	10.2	−0.4	23.6	0.0	1.4	28.3	0.0	0.7	25.5	−15.6	−100[b]	25.0	34.3	13.2
	−20	−3.2	1.7	−11.3	2199[a]	14.8	13.3	0.0	0.9	−12.3	−12.6	6.9	−12.0	−12.6	−1.9
5	+20	−30.8	−23.3	−43.6	1893[a]	20.5	48.0	1901[a]	21.3	−45.7	−24.6	−35.6	45.1	−23.9	−26.4
	−20	37.4	46.8	64.8	0.0	50.7	82.5	0.0	48.3	71.1	−28.8	−100[b]	67.7	33.1	−100[b]
6	+20	−7.7	−6.2	−12.1	2310[a]	14.8	13.9	0.0	6.6	−12.8	−8.1	−7.0	12.6	−8.1	−3.2
	−20	17.5	8.2	23.9	0.0	9.6	27.8	0.0	9.4	25.4	14.8	100[b]	25.1	22.1	19.4
7	+20	−2.4	0.2	−4.0	2198[a]	23.4	4.8	0.0	0.0	−4.3	−1.9	−1.1	−5.7	−1.7	0.0
	−20	6.3	−0.4	9.6	0.0	0.1	11.5	0.0	0.1	10.4	1.6	2.3	8.7	2.3	0.0
8	+20	−4.8	0.3	−9.0	2471[a]	20.7	−9.0	0.0	0.0	−8.1	−2.1	−1.7	−9.4	−1.9	0.0
	−20	71.4	−5.9	120.0	0.0	1.6	154.3	0.0	−1.0	131.1	−100[c]	16.6	127.8	−20.2	−100[b]
9	+20	−24.5	−30.3	−40.3	0.0	−30.1	44.8	0.0	−30.3	−42.4	−24.0	−30.5	−41.9	−23.8	−31.9
	−20	24.7	51.2	43.6	0.0	50.6	55.6	0.0	51.0	48.0	22.9	50.8	46.8	22.8	55.0
10	+20	−15.3	−15.9	−15.8	2162[a]	−4.4	−16.3	0.0	−16.4	−16.0	−14.2	−22.5	−16.0	−14.2	−17.9
	−20	22.7	27.0	23.9	0.0	28.7	24.7	0.0	28.3	24.2	−10.5	−100[b]	24.2	21.9	35.7
11	+20	−15.0	7.8	−22.6	0.0	5.3	−25.0	0.0	6.9	−23.9	−26.8	−8.4	−23.6	−26.8	−7.9
	−20	−97.3	−83.7	−99.0	0.0	81.7	−98.8	0.0	−83.1	−99.0	−80.3	−68.6	−99.0	−80.3	−70.0
12	+20	7.3	11.7	11.2	0.0	12.5	12.7	0.0	12.0	11.9	12.1	10.3	11.7	12.1	9.5
	−20	−9.5	−13.4	−14.3	0.0	−14.1	−16.0	0.0	−13.6	−15.2	−14.3	−12.1	−15.0	−14.3	−11.4
13	+20	−12.6	−16.3	−19.4	0.0	−16.8	−21.4	0.0	−16.5	−20.5	−17.0	−15.6	−20.3	−17.0	−15.1
	−20	12.9	19.9	20.1	0.0	21.0	23.1	0.0	20.3	21.6	19.7	18.3	21.2	19.7	17.4
14	+20	12.1	0.0	5.0	0.0	0.0	2.8	0.0	0.0	4.0	5.1	0.0	4.3	5.1	0.0
	−20	−12.3	0.0	6.2	0.0	0.0	−3.8	0.0	0.0	−5.1	−6.2	0.0	−5.4	−6.2	0.0
15	+20	−12.8	0.0	−8.1	0.0	0.0	−5.8	0.0	0.0	−7.0	−8.0	0.0	−7.3	−8.0	0.0
	−20	17.3	0.0	8.1	0.0	0.0	5.0	0.0	0.0	6.4	8.5	0.0	6.9	8.5	0.0
16	+20	2.9	1.1	2.9	0.0	1.1	2.9	0.0	1.1	2.9	2.8	1.1	2.9	2.8	1.1
	−20	−2.9	−1.1	2.9	0.0	−1.1	−2.9	0.0	−1.1	−2.9	−2.8	−1.1	−2.9	−2.8	−1.1
17	+20	1.6	1.3	1.1	0.0	1.4	0.9	0.0	1.3	1.1	1.5	0.6	1.1	1.5	0.6
	−20	−1.6	−1.3	−1.1	0.0	−1.4	−0.9	0.0	−1.3	−1.1	−1.5	−0.6	−1.1	−1.5	−0.6
18	+20	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0
	−20	−0.1	0.0	−0.2	0.0	0.0	−0.3	0.0	0.0	−0.2	0.0	0.0	−0.3	0.0	0.0
19	+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

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



2. Changes in dry seeded rice yield in field 5 as a function of change in crop parameters.



3. Changes in transplanted rice yield in field 5 as a function of change in the crop parameters.

higher partly because the DSR crop matured earlier, a TPR crop was planted and harvested, and mung planting was delayed and grew under lower rainfall and higher radiation levels.

For purposes of discussion, the sensitivity of the model to changes in the parameters will be classified as highly sensitive >40% change, sensitive 40% >s > 20% change, moderately sensitive 20% > ms > 5% change, and insensitive < 5% change.

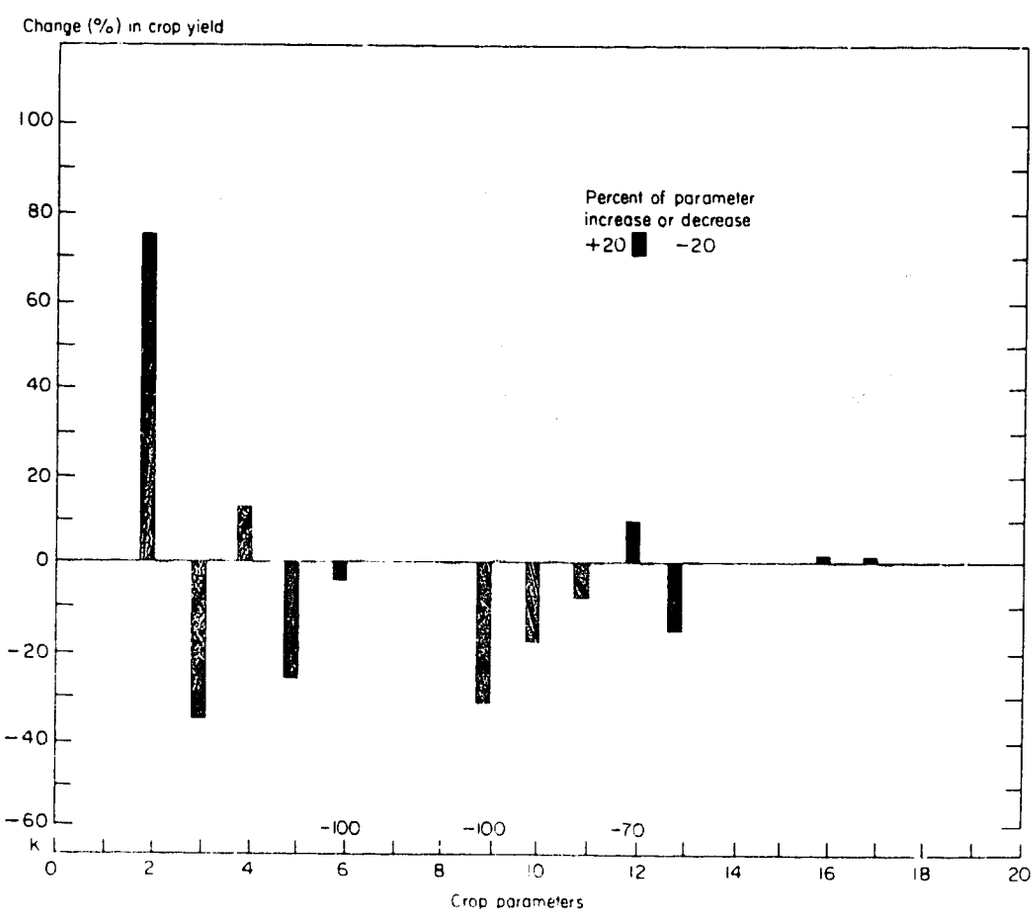
Crop parameters

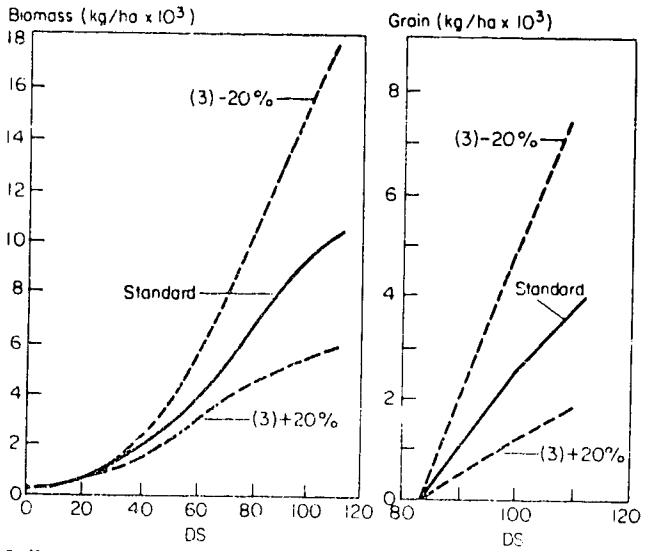
IRRIMOD simulates dry grain weight in kg ha^{-1}. The percent change in grain weight from the standard simulation caused by changing various crop parameters is given in Table 6 for each field and crop and in Figures 2-4 for field 5. (Field 5 was chosen for these figures because all three intended crops were predicted to be harvested in all cases tested.) The model's yield response to parameters 2, 3, 5, 8, 9, and 11 was highly sensitive. These are the Gompertz relative growth rate and inflection approaching maturity parameters, preanthesis rate of development, critical photoperiod for preanthesis development, proportion of preanthesis development, and optimum temperature for growth. Other parameters show either a + 100% increase or −100% decrease because crops are planted that are not planted in the standard case (Table 6, footnote a) or are not planted or planted but not harvested (Table 6, footnotes b and c). Among the highly sensitive parameters, change in the Gompertz constants produced the largest or most consistent overall changes.

The model's yield response to parameters 4, 6, 7, 10, and 13 was sensitive. Yield response predicted by 20% changes in parameters 12, 14, and 15 was moderately sensitive. The model's yield response was insensitive to parameters 1, 16, 17, 18, and 19. Among these latter parameters, a 20% change in 1 and 19 did not change the model. But they are used in the computations and if they are set to 0 the model will show a change in the output. According to Angus (pers. comm.), parameter 1 "operates strongly when approaching the potential yield of the crop. . . but not at farmer's yield," and parameter 19 "is still operating but is of little importance in a lowland rice crop or a mungbean crop with low biomass."

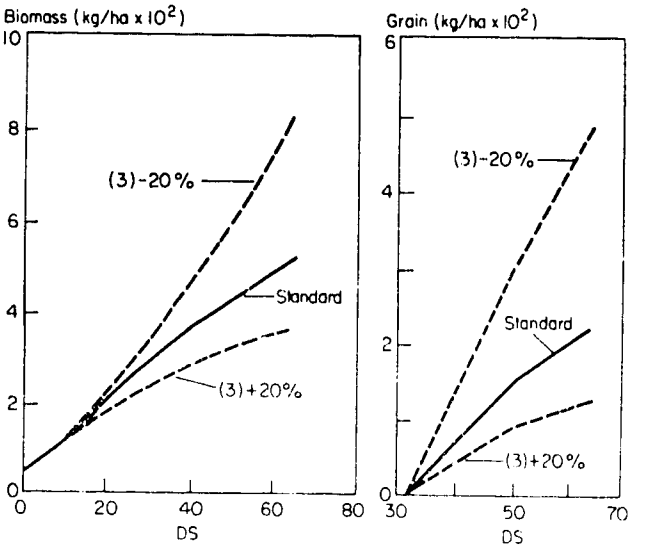
Biomass and grain mass accumulation for each of the crops grown in field 5 for crop variable 3 are shown in Figures 5-7. Comparing Figures 5 and 6 shows that the rate of dry matter accumulation is greater for DSR than TPR for the standard case and for a 20% change in crop variable 3 (the curves are steeper in Figure 5 than 6). Dry matter accumulation for mungbean (Fig. 7) was slower and less than for either rice crop (Note the change in scale on the vertical axis of Figure 7 compared to Figure 5 or 6.). However, the three crops were similarly affected by the degree

4. Changes in mung yield in field 5 as a function of change in the crop parameters.





5. Dry matter accumulation in field 5 for dry-seeded rice as changed by crop variable (parameter 3). DS = days after sowing.

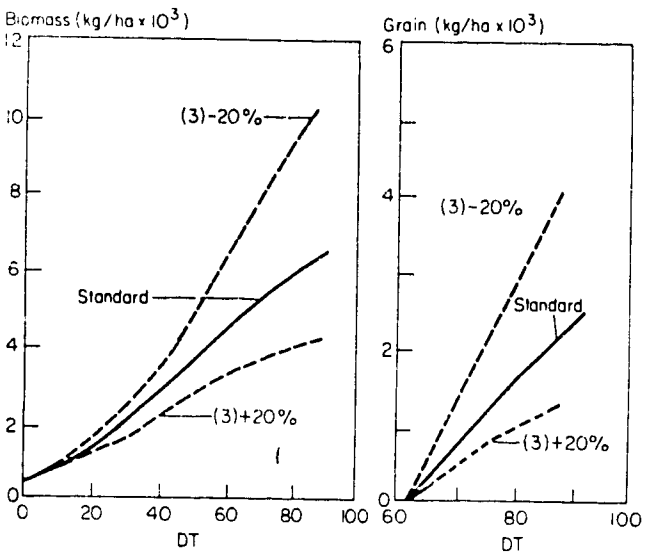


7. Dry matter accumulation in field 5 for mung as changed by crop variable (parameter 3). DS = days after sowing.

of inflection of the Gompertz function as the crop approaches maturity (Table 6).

The effects of changing the crop parameters on planting and harvesting dates are shown in Table 7. Changing only parameters 4-11 changed the dates. The model was most sensitive to parameters 5 and 8, which are preanthesis parameters (Table 1). Because changing these parameters increased or decreased the time to maturity, they caused either more or fewer crops to be planted in a crop year (1 Apr to 31 Mar) and interacted strongly with weather parameters.

The effects of changing the crop parameters on the gross income from each field and the total toposequence are shown in Table 8 and Figure 8. Gross income was calculated by multiplying the yield by the 1978 market price



6. Dry matter accumulation in field 5 for transplanted rice as changed by crop variable (parameter 3). DT = days after transplanting.

(Angus pers. comm.). Generally, parameters were equally sensitive for gross income as for yield in the earlier discussion. Tables 6 and 8 show that the overall toposequence gross income was more closely related to changes in the lower fields (4 and 5) than in the higher fields (1 and 2) because the yields in the lower fields in the toposequence were greater than those higher in the toposequence. This is especially noticeable for crop parameter 5. Table 8 shows that gross income, like yield in Table 6, was not altered by a 20% change in parameters 1 and 19. The model was most sensitive to crop parameters 3 and 11.

In IRRIMOD, the usual Gompertz function was modified (Angus 1979, Angus and Zandstra 1980) to become

$$\Delta W/\Delta t = K2.GI.We^{-K3.d} \qquad (1)$$

where W is biomass, t is time, GI is the adjusted growth index, e is the exponential base, d is the developmental time, and $K2$ and $K3$ are crop parameters. Crop parameter $K2$ is the relative growth rate or dry matter accumulation rate at the start of the simulation. Throughout the simulation it is modified by solar radiation, temperature, moisture and nitrogen stresses (indices), and by developmental time, all as part of the adjusted growth index term, GI. Developmental time is in the exponent of an exponential term of the Gompertz function and is modified by crop parameter $K3$. As parameter $K3$ increases (the degree of inflection of the S shape increases or the amount of biomass yet to be produced decreases), the total dry matter accumulation decreases and the yield decreases. The converse is true for a decrease of parameter 3. These interactions are analogous to comparing cultivars that have different growth rates and dry matter partitioning as they approach maturity. Some cultivars may add biomass very quickly and then essentially stop, that is their growth curves are very steep while others are flatter. Thus if IRRIMOD was used as a breeding program tool, it would indicate that the most desirable breed-

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

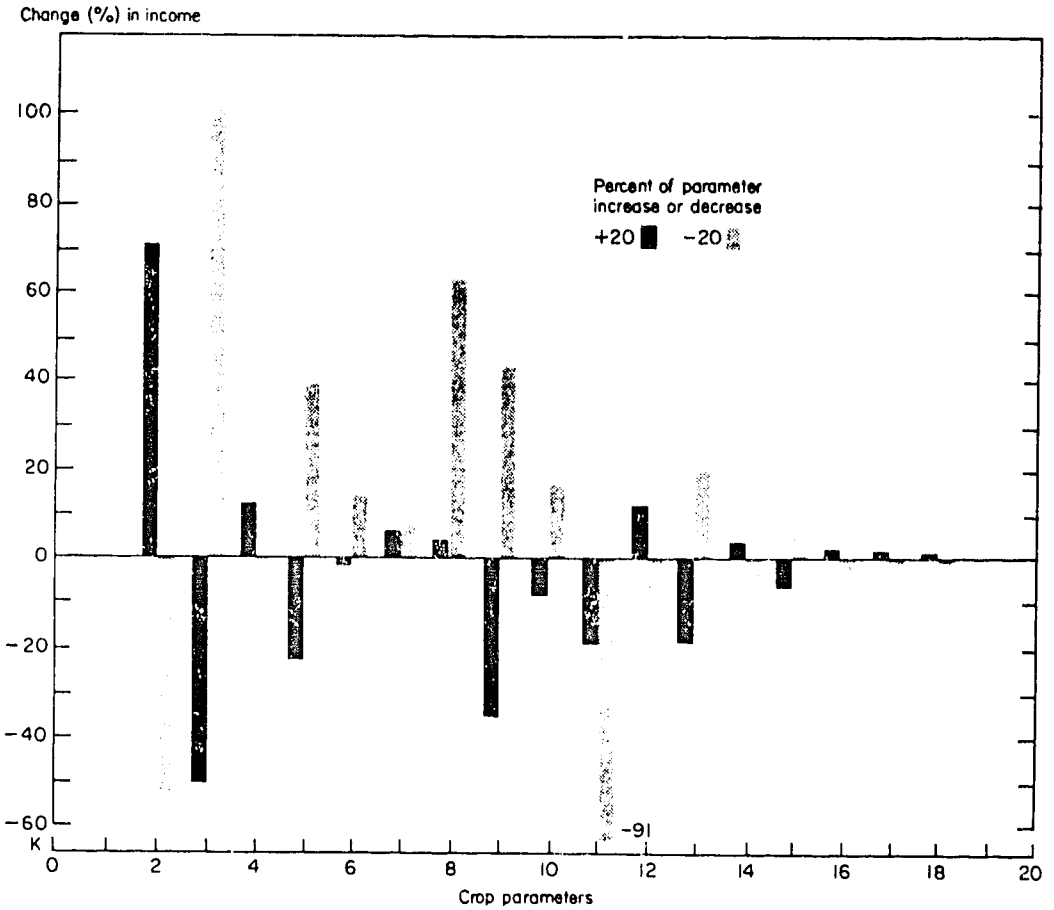
K	% change of variable	Estimated dates as no. of days of difference from the standard															
		Field 1				Field 3						Field 5					
		DSR		Mung		DSR		TPR		Mung		DSR		TPR		Mung	
		P	H	P	H	P	H	P	H	P	H	P	H	P	H	P	H
1	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	+20	0	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
3	+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
4	+20	0	−9	−10	−10	0	−8	0	0	−2	−3	0	−8	−8	−21	−14	−16
	−20	0	+4	+4	+4	0	+4	0	0	0	0	0	+4	+4	+9	0	0
5	+20	0	+19	+7	+12	0	+14	a	a	−70	−65	0	+14	+14	+25	0	+5
	−20	0	−21	−21	−29	0	−21	0	0	−15	−23	0	−20	−20	−38	−38	b
6	+20	0	+3	+3	+5	0	+4	0	0	0	+3	0	+4	+4	+7	0	0
	−20	0	−7	−7	−9	0	−7	0	0	−1	−3	0	−7	−7	−16	−9	−12
7	+20	0	+1	+1	+1	0	+1	0	0	−1	0	0	+2	+2	+3	0	0
	−20	0	−3	−3	−3	0	−3	0	0	0	0	0	−2	−2	−4	0	0
8	+20	0	+2	+2	+2	0	+2	0	0	0	0	0	+3	+3	+4	0	0
	−20	0	−39	−39	−39	0	−9	0	0	−56	−56	0	−39	−39	−51	−80	b
9	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	−4	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	+4	0	0
10	+20	0	+5	+5	+10	0	+5	0	0	0	+5	0	+5	+5	+10	0	+5
	−20	0	−7	−7	−15	0	−7	0	0	−1	−9	0	−7	−7	−15	−8	−16
11	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	−20	0	−1	−1	−1	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	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
15	+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
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	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
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	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

[a]Crop was planted but not in the standard case. [b]Crop was planted but not harvested.

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

K	% change of variable	Gross income as % change from standard					
		Field 1	Field 2	Field 3	Field 4	Field 5	Toposequence average
1	+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
2	+20	54.4	71.5	81.9	69.6	68.9	70.3
	−20	−41.8	−55.4	−56.9	−52.2	−52.2	−52.6
3	+20	−42.8	−50.0	−51.9	−50.1	−50.0	−49.7
	−20	82.2	98.9	110.6	101.7	101.0	100.7
4	+20	6.1	19.3	22.3	−7.0[b]	26.2	13.1[b]
	−20	−1.3	40.5[a]	−10.2	−11.6	−10.7	−1.0[a]
5	+20	−27.7	1.1[a]	1.8[a]	−37.1	−35.4	−22.8[a]
	−20	41.1	62.0	75.0	12.2[b]	30.9[b]	39.1[b]
6	+20	−7.1	42.2[a]	−12.3	−10.3	−9.7	−0.9[a]
	−20	13.9	21.1	23.8	−6.8[b]	23.2	13.6[b]
7	+20	−1.4	48.0[a]	−3.8	−3.0	−3.5	5.8[a]
	−20	3.7	7.7	9.0	6.3	5.3	6.5
8	+20	−2.8	49.3[a]	−7.1	−5.2	−5.6	4.2[a]
	−20	41.5	96.7	120.6	32.0[c]	44.8[b]	62.2[bc]
9	+20	−26.8	−38.3	−41.7	−34.5	−34.5	−35.6
	−20	35.0	44.9	54.6	40.1	40.2	42.8
10	+20	−15.5	32.3[a]	−16.3	−16.4	−15.7	−7.5[a]
	−20	24.4	24.9	25.5	−6.0[b]	25.2	16.3[b]
11	+20	−6.5	−17.1	−18.1	−22.5	−22.5	−19.3
	−20	−92.0	−95.6	−95.4	−88.2	−88.5	−91.1
12	+20	9.0	11.4	12.6	11.7	11.5	11.5
	−20	−11.0	−14.3	−15.5	−14.4	−14.2	−14.2
13	+20	−14.0	−18.9	−20.3	−18.6	−18.4	−18.5
	−20	15.6	20.3	22.5	20.5	20.1	20.2
14	+20	7.4	4.0	2.2	3.8	3.9	3.9
	−20	−7.6	−5.0	−3.0	−4.7	−4.9	−4.8
15	+20	−7.8	−6.5	−4.5	−6.3	−6.4	−6.2
	−20	10.6	6.5	3.9	6.1	6.3	6.3
16	+20	2.2	2.6	2.5	2.6	2.6	2.6
	−20	−2.2	−2.6	−2.5	−2.6	−2.6	−2.6
17	+20	1.5	1.2	1.0	1.1	1.1	1.2
	−20	−1.5	−1.2	−1.0	−1.1	−1.1	−1.2
18	+20	0.0	0.1	0.0	0.1	0.1	0.1
	−20	−0.1	−0.2	−0.2	−0.1	−0.2	−0.2
19	+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

[a]Crop was planted, but not in the standard case. [b]Crop was planted, but not harvested. [c]Crop was not planted but was planted in the standard case.



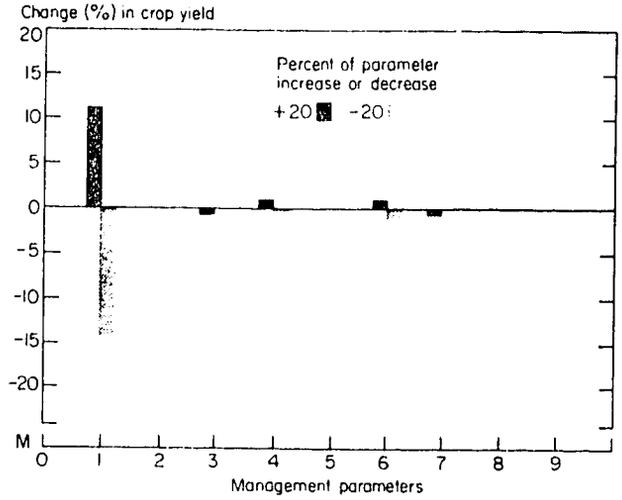
8. Changes in gross income for the toposequence as a function of change in the crop parameters.

ing lines would have a high dry matter accumulation rate and a higher fraction of dry matter to accumulate after anthesis. We also noted that yield is predicted to decline, especially for DSR, as parameter 11 is increased or decreased. Because the temperature responses of these cultivars are steep, bell-shaped curves (Angus 1979, Angus and Zandstra 1980), this may mean that a 20% change in optimum temperature is too great for the other parameters of these culti-

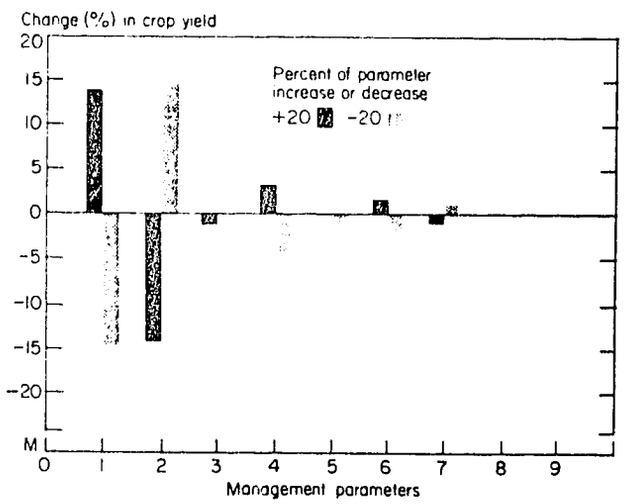
Table 9. Effect of changing management variables on simulated crop yield as a % change from the standard.

M	% 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
1	+20	7.5	20.0	10.7	0.0	20.0	13.2	0.0	20.0	11.9	13.9	20.0	11.6	13.4	20.0
	-20	-8.6	-20.0	-13.5	0.0	- 20.0	-16.1	0.0	- 20.0	-14.8	- 14.9	-20.0	-14.5	-14.9	-20.0
2	+20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- 14.1	- 1.7	0.0	-14.1	0.0
	-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	1.8	0.0	14.8	0.0
3	+20	1.1	- 0.3	0.0	0.0	0.0	- 0.9	0.0	0.0	- 0.5	- 1.4	2.2	- 0.4	- 0.8	0.0
	-20	-3.0	0.2	- 0.2	2531[a]	20.7	- 1.5	0.0	0.0	0.1	0.7	- 2.2	0.0	0.5	0.0
4	+20	0.0	0.0	2.1	2.1	0.0	1.3	0.0	0.0	1.6	3.2	0.0	1.7	3.2	0.0
	-20	0.0	0.0	- 2.4	0.0	0.0	- 1.5	0.0	0.0	- 1.8	- 3.8	0.0	- 1.9	- 3.8	0.0
5	+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	0.2	0.0	0.0	0.2	0.0
6	+20	0.0	0.0	2.1	0.0	0.0	1.3	0.0	0.0	1.6	1.9	0.0	1.7	1.9	0.0
	-20	0.0	0.0	- 2.3	0.0	0.0	- 1.5	0.0	0.0	- 1.8	- 2.2	0.0	- 1.9	- 2.2	0.0
7	+20	0.0	0.0	- 0.6	0.0	0.0	- 0.3	0.0	0.0	- 0.3	- 1.5	0.0	- 0.4	- 1.5	0.0
	-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	1.5	0.0
8	+20	0.1	0.0	0.0	2212[a]	23.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
	-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	- 1.9
9	+20	0.0	- 4.7	0.0	1845[a]	-100[b]	0.0	2138[a]	-100[b]	0.0	0.0	0.0	0.0	0.0	0.0
	-20	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	-100[c]	-19.3	0.0	0.0	0.0

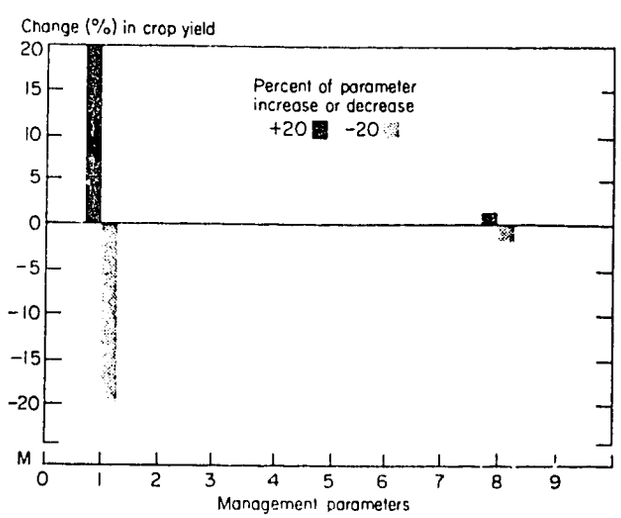
[a]Crop was planted but not in the standard case. [b]Crop was planted but not harvested in this crop year. [c]Crop was not planted but was planted in the standard case.



9. Changes in dry seeded rice yield in field 5 as a function of change in the management parameters.



10. Changes in transplanted rice yield in field 5 as a function of change in the management parameters.

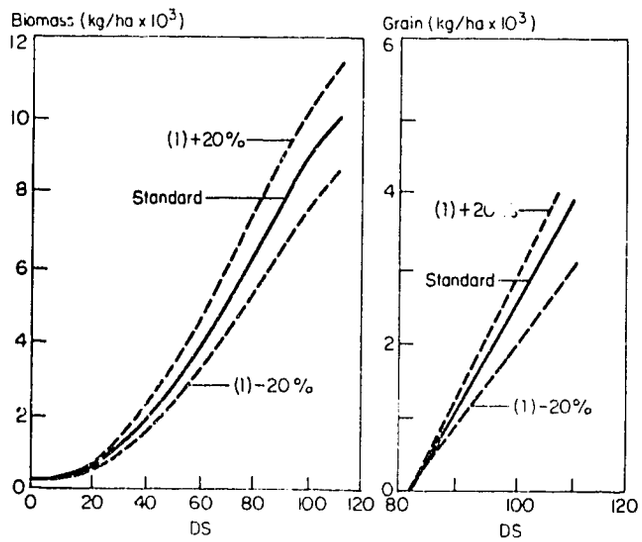


11. Changes in mung yield in field 5 as a function of change in the management parameters.

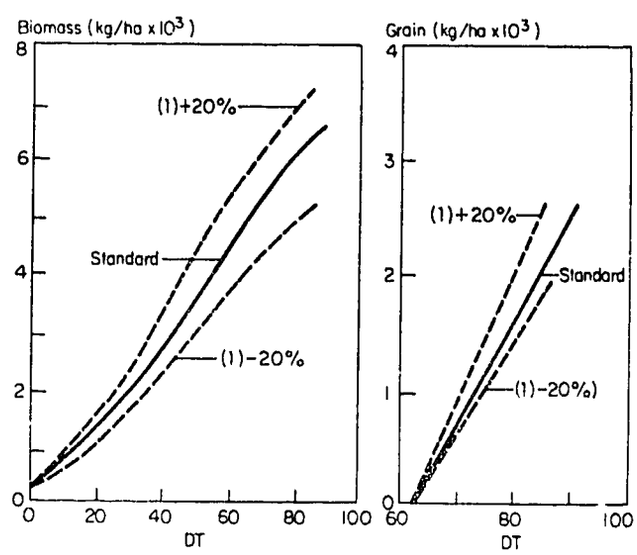
vars. Thus, as a tool in varietal selection, IRRIMOD would show that potential cultivars and species should be planted where their optimum temperature for growth matches the average temperature of the area.

Management parameters

The percent changes in grain weight from the standard simulation caused by changing management parameters are given in Table 9 for each field and crop, and in Figures 9-11 for field 5. The model generally was less sensitive to management parameters than to crop parameters. The model was sensitive to parameter 1, initial biomass at planting. Other parameters produced a higher or lower than 20% change for individual crops, because extra crops were being



12. Biomass accumulation and grain dry weight accumulation for dry seeded rice in field 5 as changed by changes in management parameter 1. DS = days after sowing.

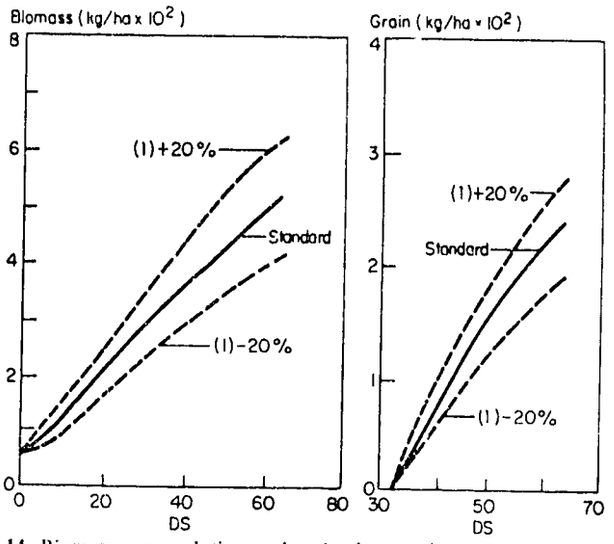


13. Biomass accumulation and grain dry weight accumulation for transplanted rice in field 5 as affected by changes in management parameter 1. DT = days after transplanting.

planted or not planted (Table 9 footnotes). The model was moderately sensitive to parameters 2, and perhaps 9, and insensitive to all other management parameters. However, the model did not have any management parameter with a 0 response to a 20% change.

Comparing Figures 9 and 10 indicates that in field 5 TPR was more responsive to management parameters than DSR. Figure 11 shows that mung was more responsive to parameter 1 than either rice crop. If this is interpreted as planting or seeding rate rather than weights of individual seeds or plants, then this response indicates that mung is more responsive to plant population per ha than rice.

The effect of management parameter 1 on dry matter accumulation is shown in Figures 12-14 for the three crops in field 5. As in the earlier analysis, the rate of biomass accumulation was highest for DSR, followed by TPR and least for mung. As in Figure 11, the percent change in mung is greater than for either rice crop.



14. Biomass accumulation and grain dry weight accumulation for mung in field 5 as affected by changes in management parameter 1. DS = days after sowing.

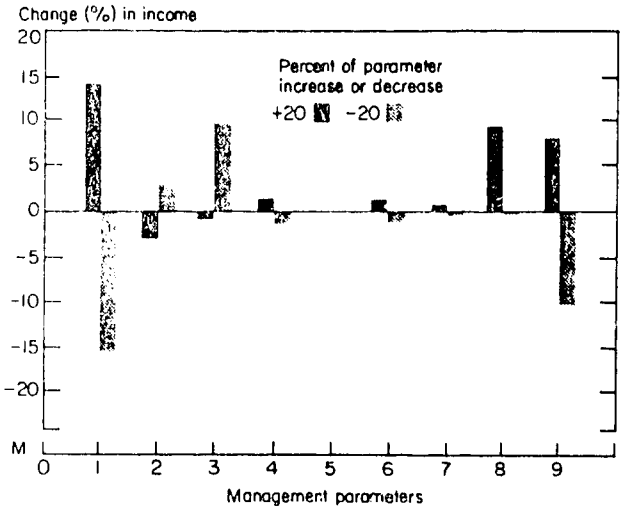
Table 11. Effect of changing management variables on gross income as a % change from the standard.

M	% change variable	Gross income as % change from standard					
		Field 1	Field 2	Field 3	Field 4	Field 5	Topo-sequence average
1	+20	12.3	12.5	14.7	13.6	13.4	13.4
	−20	−13.0	−14.8	−17.0	−15.6	−15.5	−15.4
2	+20	0.0	0.0	0.0	− 4.9	− 4.6	− 2.7
	−20	0.0	0.0	0.6	5.1	4.8	2.8
3	+20	0.6	0.0	− 0.7	− 0.4	− 0.5	− 0.3
	−20	− 1.7	57.6[a]	− 1.2	0.0	0.2	9.8
4	+20	0.0	1.7	1.0	1.9	1.9	1.6
	−20	0.0	− 1.9	− 1.1	− 2.2	− 2.2	− 1.8
5	+20	0.0	0.0	0.0	0.0	0.0	0.0
	−20	0.0	0.0	0.0	0.1	0.1	0.0
6	+20	0.0	1.7	1.0	1.5	1.5	1.3
	−20	0.0	− 1.9	− 1.1	− 1.7	− 1.7	− 1.5
7	+20	0.0	− 0.5	− 0.2	− 0.7	− 0.7	− 0.5
	−20	0.0	0.0	0.0	0.5	0.5	0.3
8	+20	0.0	51.5[a]	0.0	0.0	0.2	9.1
	−20	0.0	0.0	0.1	0.0	− 0.3	− 0.1
9	+20	− 1.8	19.5[ab]	27.7[ab]	0.0	0.0	7.7
	−20	0.0	0.3	0.0	−36.2[c]	0.0	−10.2

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

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

M	% change of variable	Estimated dates as no. of days of difference from the 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	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
2	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	+3	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	−3	0	0
3	+20	−2	−2	−2	−2	−2	−2	0	0	0	0	−2	−2	−4	−4	0	0
	−20	+2	+1	+1	+1	+2	+2	0	0	0	0	+1	+1	+3	+3	0	0
4	+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
5	+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
6	+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
7	+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
8	+20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−3	−3
	−20	0	0	0	0	0	0	0	0	+2	+2	0	0	0	0	+4	+4
9	+20	0	0	−27	−27	0	0	a	a	−120	b	0	0	0	0	0	0
	−20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	



15. Changes in gross income for the toposequence as a function of change in the management parameters.

The effects of changing management parameters on simulated planting and harvesting dates are shown in Table 10. Only changes in parameters 2, 3, 8, and 9 caused changes in the planting dates, these changes were not as great as for the crop parameters except for parameter 9, the date after which a second crop was not considered.

The effects of changing management parameters on simulated gross income for each field and the total toposequence are shown in Table 11 and Figure 15. The model was only moderately sensitive to parameter 1 in terms of gross income. Parameters 3, 8, and 9 interact with the weather parameters caused by changes in the planting and harvesting dates.

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