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CELSS Scenario Analysis: Breakeven Calculations

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CELSS

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CELSS

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INTRODUCTION

PURPOSE

This report summarizes the results of effort aimed toward the development of a rudimentary model that illustrates the relative mass requirements of food production components in a controlled ecology life support system (CELSS) based on regenerative concepts. The report is intended as a working paper which can provide a basis for further model development and analysis.

The model and analytic results can be useful for developing an understanding of the mass requirements for food production in a CELSS and how these requirements compare with food resupply requirements. Such an understanding aids in making knowledgeable decisions about research investment options in regenerative life support. More importantly, the documentation of the model and results reveals gaps in knowledge and thereby provides guidance for improving the model and the analysis procedures.

BACKGROUND

The need for life support options based on regenerative methods becomes increasingly important from a logistics standpoint for long duration missions. This need has been recognized and discussed in several workshops and reports (1,2,3,4,5).

Other studies, reports, and papers have proposed using scenario analyses to help evaluate research progress and to help program managers assess technology options for regenerative systems (6,7,8,9,10,11,12). The scenario analysis approach, although utilized in these prior studies, has heretofore not been documented in the detail necessary for comparative studies by other researchers. This report provides documentation of the initial model and illustrates its use and its sensitivity to changes in assumptions and parameter values. In addition to documenting the overall scenario model, this report also updates the diet assumed for the 1977 summer study (e.g., see 9).

MODEL SCOPE AND STRUCTURE

SCOPE

Assumptions

The model is a simple deterministic formulation that equates the mass required for food supply under two different scenarios: A) complete resupply of diet materials (baseline scenario) and B) part of the diet supplied by food grown in the space habitat by regenerative methods (alternative scenario). The model thus uses time as the dependent variable, permitting the calculation of a "breakeven time," which may be considered as the mission duration for which the total mass required for supplying dietary requirements under the baseline scenario equals the mass required under the alternative scenario.

Several simplifying general assumptions are implicit in the resulting formulation:

1. Mass requirements for the baseline food supply scenario are linear with time.
2. Total mass requirement for each scenario may be represented by a simple summation of component masses. Each component represents a particular necessary function and may further be subdivided into expressions representing subcomponents or macrocategories of design factors.
3. Several functional requirements which may be substantially different in the two scenarios are included from the model:
   - energy collection, power generation, energy storage, and waste energy rejection;
   - human and food supply waste processing requirements; and
   - food and waste storage requirements.
4. Food production by conventional biological growth (plant photosynthesis) is a viable candidate food production process. (See also reference 13.)

Focus and Limitations

The above assumptions indicate the model's focus on the food production function itself and not on components and functions which may be heavily dependent on the choice of food supply. The model, at this stage of development, therefore is useful primarily for comparing conventional food supply alternatives which are judged not to have a substantial difference in requirements for (or impacts on) energy and waste processing functions. The results of model calculations also can indicate orders of magnitudes of mass requirements on an absolute scale, providing a starting point for assessing alternative food supply scenarios and for determining the relative mass of food supply components.

MODEL STRUCTURE

Baseline Scenario (Resupply)

The baseline scenario is characterized by full resupply of necessary diet materials. The diet requirements are often given on a person-day or person-year basis. By letting $\underline{M}_R$ by the resupply mass required for food (g/person-year), the food resupply mass for a population of N_p for a period of T years is given by

$$(\underline{M}_R)(N_p)(T). \qquad (1)$$

To this mass should be added the mass required for air revitalization. Engineering considerations (14) suggest that this mass can be modeled by an expression representing a fixed mass and plus a mass which is linearly dependent on the number of persons:

$$M_o+(M_{ov})(N_p). \qquad (2)$$

The mass required for the resupply is thus given by the sum of (1) plus (2).

Alternative Scenario

The alternative scenario is characterized by recycling of nutrients, utilizing plants for growing food. The mass required for growing and processing the food may be represented by the sum of five mass components: the food-producing biomass (M_B), the mass of the harvesting equipment (M_H), the food production system mass (system components for plant growth, excluding the plant biomass itself, M_{PS}), the mass of the food processing equipment (M_{FP}), and the mass of the water of transpiration (M_{WT}) required in the plant growth environment (including the atmospheric/vapor phase and the nutrient reservoir but excluding the water contained in the plant biomass). Each mass would be given in grams (or kilograms) unless other dimensions are specified. The total mass for the alternative scenario is given by

$$M_B + M_H + M_{PS} + M_{FP} + M_{WT}. \quad (3)$$

Calculations for each of the components are given in the following paragraphs.

Food Producing Biomass. The total biomass required for the food production function is given by the sum of the biomass required for each of the individual foods in the diet. Letting M_{Bj} be the biomass required to produce the daily dietary requirement of one person for food j, the total productive biomass is given by

$$\sum_j (\underline{M}_{Bj})(N_p). \quad (4)$$

$\underline{M}_{Bj}$ is calculated from the dietary requirements which are met by the food produced by the plants. If the daily diet amount of food j is $\underline{R}_{ej}$, this is equal to the production rate of fresh edible food (g/person-day) and thus the total biomass harvest rate, $\underline{B}_{oj}$ (g/person-day) is given by

$$\underline{B}_{oj} = (\underline{R}_{ej})/(e_{Bj}), \quad (5)$$

where e_{Bj} is the edible fraction (fresh). Assuming a simplified model of linear biomass growth over time, with t_H as the total growing period (time to harvest), then

$$\underline{M}_{Bj} = (\underline{B}_{oj})(t_{Hj}/2). \quad (6)$$

Harvesting Equipment. Food harvesting equipment for a CELSS has not been designed, and much of the harvesting functions may be fulfilled manually. Grain products (e.g., wheat) may be an exception, and this model assumes a single grain harvester (plot harvester) with a mass of 800 kg (15). That is, the initial assumption for harvesting equipment requirements is:

$$M_H = 800. \quad (7)$$

Food Production System. The food production system consists of the components necessary to sustain productive plant growth in a controlled environment. These components include lighting, atmospheric control, plant support, and control components. Estimates for these components, based initially on a design for earth-based phytotron facilities, have been placed into three categories: (1) fixed mass components, whose mass is independent of the total growing area required (e.g., control components), (2) an unscaled mass which is linearly related to the size of the growing area (e.g., lighting components), and (3) a scaled mass which increases with the size of the growing area by a power relationship (e.g., atmospheric control components). The last category uses the empirical engineering rule of 0.6 scaling, in which the mass requirement increases with the 0.6 power of the area. Such a scaling is consistent with components whose capacity would be related to volume rather than area, for example. (Appendix A gives the individual components of a ground-based controlled environment (phytotron-type) system, their mass, and the estimated masses for the three model categories.)

The model calculation for the food production system mass (M_{PS}) is therefore

$$M_{PS} = M_{PSC} + (M_a)(A) + (M_{as})(A_B)^{0.6}, \qquad (8)$$

where M_{PSC} is the total fixed (control component) mass, A is the growing area (or total illuminated area), M_a is the factor for the unscaled (linearly related to area) mass, and M_{as} is the scaled area factor.

The biomass growing area required per person ($\underline{A}_B$, in m^2/person) is calculated from the dietary requirements for the diet components and the plant productivities. For food j, the required area is given by

$$\underline{A}_{Bj} = (\underline{R}_{ej})/[(P_j)(e_{Bj})], \qquad (9)$$

where $\underline{R}_{ej}$ is the dietary requirement (required fresh edible production rate), e_{Bj} is the edible fraction (fresh) of the total biomass harvested daily, and $\underline{p}_j$ is the biomass productivity, or total biomass growth rate (g/m^2-day).

Food Processing Equipment. Food processing equipment mass is estimated from data on current food preparation system technology and assumed engineering developments (16). The mass assumed for this equipment is

$$M_{FP} = K(N_p)^x, \qquad (10)$$

where the factor K and the power x are determined by fitting a curve to the data for populations of 10 and 100 persons, and these parameters are 302.7 and 0.415, respectively, for M_{FP} in kilograms.

Water Reservoir Mass. The final component of mass in the alternative scenario is the water of transpiration, M_{WT} (kg). This mass includes the atmospheric (vapor phase) moisture in the plant growth chamber and the mass of the nutrient reservoir, but excludes the water in the plant biomass. Plants differ in the amount of water they transpire daily, but the amount can be modeled by a linear relationship to the dry biomass of the plant. Consequently, in order to compare different plants and different diets, the model incorporates a parameter which represents the number of days of transpired water assumed to be required in the system for the growing biomass. For plant j, the water of transpiration mass, M_{WTj} is given by

$$M_{WTj} = (10)(\underline{M}_{Bdj})(N_p)(T_r), \tag{11}$$

where $\underline{M}_{Bdj}$ is the dry biomass (kg/person) of plant j, 10 is the empirical factor representing the ratio of water mass transpired (per day) to the plant's dry biomass, N_p is the population, and T_r is the design factor representing the number of days of transpiration water required by the system.

EXAMPLE CALCULATIONS

DIET AND PLANT GROWTH ASSUMPTIONS

Diet Basis

The diet requirements assumed for both the baseline and alternative scenarios are based on a "thrifty food plan." This diet is characterized by less consumption of animal tissue and somewhat more grain consumption than actual consumption patterns of food stamp recipients. The diet assumed for the model is the thrifty plan with small variations due to the assumed percentage of waste and to minor diet variations. Table 1 compares the actual food consumption pattern, the thrifty diet, and the diet assumed for the model. Note that the last column in the table also is equivalent to the required production rate of edible fresh food.

Plant Growth Rates

Plant growth data are taken from the literature on crop yield and plant productivity studies. The other model parameters related to ratios of fresh and dry weights, edible and total biomass, etc., are taken from the same literature. Table 2 presents these and the related calculated values for the major food plants in the assumed diet.

STORAGE AND RESUPPLY ASSUMPTIONS

For the baseline scenario, food must be stored or resupplied. The mass of this stored or resupplied food is assumed to be linearly related to the edible dry biomass, with the small residual moisture content and packaging mass being 53% of the dry mass. The daily resupply mass for food j is therefore

$$\underline{M}_{Rj} = (1.53)EB_{dj}, \tag{12}$$

where EB_{dj} is the edible biomass, dry, of food j.

The mass required for air revitalization, a function assumed to be performed adequately by the plants in the alternative scenario, is given by expression 2 for the baseline scenario. From reference 14, the total mass for air revitalization has a small (90.4 kg) fixed component and a larger variable component. The parameters for expression 2 are $M_o = 90.4$ and $M_{ov} = 415.8$.

Table 1. Food Quantities - Comparison of Consumption Pattern, Thrifty Diet, and Model Assumptions[1]

(fresh weight, grams/person-day)

	Food Consumption Pattern[2]	Thrifty Food Plan[3]	Diet Assumed for Model Calculations (R_{ej})	
A. Milk,cheese,ice cream	548.4	404.5		399.8
B. Meat,poultry,fish	209.2	196.5		196.5
C. Eggs	41.1	34.3		30.2
D. Dry beans,peas,nuts	16.2	28.5	Beans	16.2
			Peanut Butter	11.7
E. Potatoes	84.3	131		131
F. Dark green, deep yellow vegetables	24.3	25.3	Leaf Cabbage	13.6
			Carrots	11.7
G. Citrus fruit,tomatoes	110.3	116.7	Tomatoes[4]	116.7
H. Other vegetables,fruit	230.2	239.3	Green Beans	44.8
			Head Cabbage	12.3
			Lettuce	20.1
			Melons[5]	253
			Peas	9.7
I. Grain products		Cereal 57.7	Wheat Equiv.	352
		Flour 59.7		
		Bread 148.5		
		Other Bakery Products 86.3		
J. Fats, oils	38.9	61.6		61.6
K. Sugar, sweets	55.1	55.8		55.8
L. Accessories	Not Given	Not Given		80.4

Notes:

[1] Adapted from "The Thrifty Food Plan" (17) and "Report to J. Spurlock" (BSSG) from Marcus Karel (18).

[2] Based on National Survey of Food Stamp and Food Distribution Program Recipients, November, 1973 (Average 4-person Household); from "The Thrifty Food Plan" (17).

[3] Based on 20-54 year-old male nutritional requirements; amounts for some groups allow for approximately 5% discard and waste (e.g., egg shells).

[4] Tomatoes replace oranges on equal mass basis.

[5] Melons replace apples and bananas on 2.48 g per gram basis.

Table 2. Plant Productivity Parameters for Major Foods

Column	1	2	3	4	5	6	7	8	9	10	Reference
Parameter*	R_e	t_H	TB_d	P	EB_d	EB_f	e_B (6÷4)	$\underline{B}_o$ (1÷7)	$\underline{A}_B$ 1÷(4x7)	w_e 1-(5÷6)	
Food											
Dry Beans	16.2	47	43.1	204.3	21.1	24.3	.119	136.1	.67	.132	19
Peanut Butter	12.3	110	49.5	355.0	8.2	9.4	.026	473.1	1.33	.126	20
Leaf, Head Cabbage	25.9	30	10.4	180.8	9.9	172.1	.952	27.2	.15	.942	21
Carrots	11.7	80	43.6	315.6	21.3	154.2	.489	23.9	.08	.862	21
Tomatoes	116.7	215	7.9	113.5	6.2	95.0	.84	138.9	1.22	.93	22
Potatoes	131.0	120	20.2	134.6	13.7	97.9	.727	180.2	1.34	.86	23
Green Beans	44.8	60	108.9	920.6	26.3	305.2	.332	134.9	.15	.914	24
Lettuce	20.1	28	11.6	221.1	8.5	161.3	.730	27.5	.12	.947	25
Melons	253.0	107	32.9	396.5	19.9	298.9	.754	335.5	.85	.933	26
Peas	9.7	50	15.6	99.9	0.6	3.7	.037	262.2	2.62	.838	27
Wheat	352.2	196	148.4	505.3	58.5	67.2	.133	2648.1	5.24	.129	24
Totals	993.6		486.1					4387.6	13.77		

* R_e = daily requirement (g-person^{-1}-day^{-1}, fresh); t_H = time to harvest (days); TB_d = total biomass, dry; P = productivity; EB_d = edible biomass, dry; EB_f = edible biomass, fresh (all g-m^{-2}-day^{-1}); e_B = edible fraction, fresh; $\underline{B}_o$ = biomass harvest rate (g-person^{-1}-day^{-1}); $\underline{A}_B$ = growing area required (m^2-person^{-1}); w_e = fraction moisture, edible.

BREAKEVEN CALCULATION PROCEDURE AND RESULTS

The calculation of times (years) for which the baseline and alternative scenario mass requirements are equal initially was performed using two programs for a programmable hand calculator (HP-67). These programs, described in Appendixes C and D, permit rapid evaluation of detailed scenarios and the evaluation of the model's sensitivity to changes in single parameter values. Appendix B summarizes the nomenclature conventions for both programs.

The first program (Appendix C) calculates the plant productivity, growing area requirements, and the other calculated plant parameters from the fresh and dry total and edible biomass productivity factors, the dietary requirements, and the growing period (time to harvest) for individual cultivars.

The second program uses the results of the first and design parameters (population and assumed parameter values for the growing environment and food processing component masses) to calculate the mission duration for which the mass requirements of the two scenarios are equal. This program is a preliminary, incomplete version of the model outlined in the text above. Specifically, the program in Appendix D does not include expression (2), the mass assumed to be required for air revitalization components in the baseline scenario. Therefore, the program is particularly useful for calculating breakeven times for individual food items/cultivars (scenario comparisons in which air revitalization is required both for the baseline case and an alternative that involves limited on-board food production).

Table 3 presents the results of calculations for the major plant-produced foods. Note that wheat has the earliest breakeven time, followed by beans (dry and green), melons, and potatoes, with peas having the longest breakeven time.

For the alternative scenario in which virtually all plant-derived food is grown, with the biomass providing both food production and air revitalization functions, the breakeven time is 12.4 years, as shown in Table 4. This table also shows the results of modifying the initial values of the parameters to generate additional alternative scenarios for comparison with the resupply case.

Table 3. Breakeven Analysis Results - Comparison of Resupply and Regenerative Scenarios

Assumptions: Resupply mass = 1.53 x dry mass of food required.
Initial alternative scenario parameter values:

$N_p = 10$ $M_{fp} = 0$ $M_{PSC} = 15.88$ $M_{as} = 122$

$T_r = 1$ $M_H = 0$ $M_a = 83.2$

Food	(Baseline) Resupply Mass ($kg\text{-}person^{-1}\text{-}yr^{-1}$)	(Alternative) Biomass Holdup ($kg\text{-}person^{-1}$)	Growing Env. Equip. Mass (M_{PS})(kg)	M_{WT} (kg)	T_{BE} (yrs)
A. Dry Beans	7.87	3.22	955.3	69.9	13.1
B. Peanut Butter	6.00	25.6	1677	355.5	34.3
C. Cabbage	.84	.407	361.8	2.4	43.4
D. Carrots	.90	1.01	189.2	13.9	22.7
E. Tomatoes	4.56	14.9	1578	109	37.3
F. Potatoes	10.24	10.8	1710	162.3	18.4
G. Green Beans	2.15	4.14	296.3	46.6	16.1
H. Lettuce	.60	.402	266.8	2.1	44.9
I. Melons (for Apples)	4.00	7.64	578.5	63.4	16.2
(for Bananas)	2.33	4.46	381.0	37.0	18.3
(for Fresh Fruit)	3.13	5.94	475.1	49.3	16.9
J. Peas	.88	6.54	3061	102.1	360
K. Grain (Wheat)	171.3	259.5	5688	7629	7.9

Table 4. Breakeven Analysis, All Plants Combined

Initial Values

$M_{TR} = 214.8$ (kg $person^{-1}$-yr^{-1})	$M_{PSC} = 15.9$ (kg)
$N_p = 10$ (persons)	$M_a = 83.2$ (kg m^{-2})
$T_r = 1$	$M_{as} = 122$ (kg m^{-2})
$M_{fp} = 787^{*}$	$\underline{A}_B = 13.8$ (m^2-$person^{-1}$)
$\underline{M}_B = 344.6$ (kg $person^{-1}$)	$M_o = 90.4$
$\underline{M}_{Bd} = 86.4$ (kg $person^{-1}$)	$M_{ov} = 415.8$
$M_H = 800$ (kg)	

Other values given in Table 2.

*Corresponding to $K = 302.7$ and $x = 0.415$ in equation (10).

Results

Scenario	Breakeven Time (T_{BE}, Years)
A. Initial values, above	12.4
B. As A, with $M_o = M_{ov} = 0$	12.4
C. As A, with peas resupplied	9
D. As C, with $T_r = 1.1$	8.5
E. As C, with peanut butter resupplied	9.7
F. As C, with NP = 100	8.5
G. As E, with $N_p = 100$	7.7

DISCUSSION

ISSUES FOR FURTHER STUDY

The results of applying the model thus far indicate several issues which should be considered further. These issues are outlined in the following paragraphs.

Plant Productivity Measures

The area of the growth chamber has a relatively large impact on the overall CELSS mass requirements. Consequently, plant productivity, as measured by the yield of edible (and digestible) biomass per unit area, is an important consideration.

Another contributor to total mass of the regenerative system is the standing biomass, or "biomass holdup." Plants which have low biomass holdup for a given edible production are thus desirable. (Note that time to harvest, or maturity period, is not directly, or solely, an adequate measure of productivity.)

Functional Components

The results indicate that the components associated with the growth chamber (scaled and unscaled components) are significant contributors to the total mass. Reductions in the mass required for these components (e.g., lighting) should be possible.

CONCLUSIONS

The model, although limited in scope, provides a useful starting point for analyzing alternative diet and plant growth scenarios. Further refinement is underway to improve the model's utility and to facilitate its application by other researchers.

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Appendix A

CONTROLLED ENVIRONMENT WEIGHT ESTIMATES

System Component	Estimated Weights (lbs)			
	Initial[1]	Optimistic[2]		
	Per $.98m^2$	(Net) Fixed	(Net) Per $.98m^2$	(For .6 scaling) Per $.98m^2$
1. Panels	612	0	0	0
2. Fan Coil Assembly	150	-	-	(Include in 6B)
3. Refrigeration Cond. Unit	185	-	(Include w/heat rejection)	-
4. Lighting	150	-	150*	-
5. Control Console	76	25	-	-
6A. Humidification	33			33
b. Dehumidification	205			200
7A. Exhaust & Make up Air Blower	76	-	-	-
B. CO_2 Analyzer	-	10	-	-
8. Plant Support Structure	150		30	
9. Misc. Components (Wireways-50; Insulation-10; Piping-50; Vibration Links-5; Wires-30; Valves, etc.-15)	160		-	30
Total (lb)	1797	35	180	263
(kg)	812.12	15.88	81.65	119.30
($kg\text{-}m^{-2}$)	827.6	NA	83.21	121.57

[1]David Raper, personal communication (estimates from Environmental Specialties, Raleigh, North Carolina).

[2]Estimates by Mike Modell, Jack Spurlock, Dave Raper, and Bob Mason (79/06/26).

*Reduction should be possible.

Appendix B

NOMENCLATURE AND CONVENTIONS

Conventions

Subscript j refers to type of crop in cultivar.

Total biomass defined as edible and inedible.

Underbar: per person basis.

Parameter or Variable	Symbol
Growing area (m^{-2}-person^{-1})	$\underline{A}_{Bj}$
Total biomass harvest rate (g person^{-1}-day^{-1})	$\underline{B}_{oj}$
Edible fraction, fresh	e_{Bj}
Mass requirement for growing area, unscaled components (kg-m^{-2})	M_a
Mass requirement for growing area, scaled components (kg-m^{-2})	M_{as}
Dry biomass holdup (g-person^{-1})	$\underline{M}_{Bdj}$
Food processing equipment mass for 10 persons (kg)	M_{fp}
Mass of food harvesting equipment (kg)	M_H
Total growing area equipment mass (kg)	M_{PS}
Mass of control equipment for food production module (kg)	M_{PSC}
Additional mass required for alternative scenario above that required for baseline scenario	M_{TP}
Mass required for resupply/storage of food j (kg-person^{-1}-yr^{-1})	$\underline{M}_{TRj}$
Mass of (transpiration) water required for adequate humidity and nutrient reservoir	M_{wt}

Parameter or Variable (cont.)	Symbol
Population	N_p
Total growth rate of fresh biomass (g m^{-2} day^{-1})	$\underline{P}_j$
Production rate of fresh edible food (g $person^{-1}$ day^{-1}) (Set equal to daily requirement)	$\underline{R}_{ej}$
Harvest waste, fresh (g $person^{-1}$ day^{-1})	$\underline{R}_{wj}$
Breakeven time (yrs); mission duration for which mass requirements of baseline and alternative scenarios are equal	T_{BE}
Total time to harvest (days)	t_{Hj}
Number of days of transpiration supply assumed	T_r
Fraction of water in total biomass	w_{Bj}
Fraction of water in edible portion	w_{ej}
Fraction of water in inedible portion	w_{wj}
Harvest waste water (g $person^{-1}$ day^{-1})	$\underline{W}_{wj}$

Appendix C

HP-67 PROGRAM FOR CULTIVAR CALCULATIONS

<u>Storage</u>

0	$\underline{R}_{ej}$	5	$P_j = TB_{fj}$
1	w_{ej}	6	$\underline{B}_{oj}$
2	w_{wj}	7	(TB_{dj})
3	e_{Bj}	8	(EB_{dj})
4	t_{Hj}	9	(EB_{fj})

<u>Program Instructions</u>

1. Key in TB_{dj}, press [ENT]
2. " " TB_{fj}, " "
3. " " EB_{dj}, " "
4. " " EB_{fj}, " [A]
5. " " t_{Hj}, " [ENT]
6. " " $\underline{R}_{ej}$, " [B]
7. Read out:

1) $\underline{R}_{ej}$	7) w_{ej}
2) w_{ej}	8) $\underline{A}_{Bj}$
3) w_{wj}	9) $\underline{B}_{oj}$
4) e_{Bj}	10) $\underline{M}_{Bj}$
5) t_{Hj}	11) $\underline{R}_{wj}$
6) P_j	12) $\underline{W}_{wj}$

AGRICULTURAL DATA INPUT CONVERSIONS

Input Data Arrays

TB_{dj}: Total biomass, dry (g m^{-2} day^{-1})

TB_{fj}: Total biomass, fresh (g m^{-2} day^{-1})

EB_{dj}: Edible biomass, dry (g m^{-2} day^{-1})

EB_{fj}: Edible biomass, fresh (g m^{-2} day^{-1})

Derived Variable Arrays

w_{ej}: Fraction of water in edible portion

w_{wj}: Fraction of water in inedible portion

e_{Bj}: Edible fraction, fresh

P_j: Total growth rate of fresh biomass (g m^{-2} day^{-1})

Sequence of Calculations

$$w_{ej} = \frac{EB_{fj} - EB_{dj}}{EB_{fj}} = 1 - EB_{dj}/EB_{fj}$$

$$w_{wj} = \frac{(TB_{fj} - EB_{fj}) - (TB_{dj} - EB_{dj})}{(TB_{fj} - EB_{fj})} = 1 - \frac{(TB_{dj} - EB_{dj})}{(TB_{fj} - EB_{fj})}$$

$$e_{Bj} = \frac{EB_{fj}}{TB_{fj}}$$

$$P_j = TB_{fj}$$

ALGORITHM FOR AGRICULTURAL PRODUCTION

Design Variables

N_p : Population

$\underline{R}_{ej}$: Production rate of fresh edible food (g person^{-1} day^{-1})

Data Arrays

w_{ej} : Fraction of water in edible portion

w_{wj} : Fraction of water in inedible portion

e_{Bj} : Edible fraction, fresh

t_{Hj} : Total time to harvest (days)

$\underline{P}_j$: Total growth rate of fresh biomass (g m^{-2} day^{-1})

Derived Variables

w_{Bj} : Fraction of water in total biomass

$\underline{A}_{Bj}$: Growing area (m^2 person^{-1})

$\underline{B}_{oj}$: Total biomass harvest rate (g person^{-1} day^{-1})

$\underline{M}_{Bj}$: Total biomass holdup (g person^{-1})

$\underline{R}_{wj}$: Harvest waste, fresh (g person^{-1} day^{-1})

$\underline{W}_{wj}$: Harvest waste water (g person^{-1} day^{-1})

Sequence of Calculations

1. $w_{Bj} = w_{ej}\ e_{Bj} + w_{wj}\ (1-e_{Bj})$
2. $\underline{A}_{Bj} = \underline{R}_{ej}/\underline{P}_j\ e_{Bj}$
3. $\underline{B}_{oj} = \underline{R}_{ej}/e_{Bj}$
4. $\underline{M}_{Bj} = \underline{B}_{oj}\ t_{Hj}/2$
5. $\underline{R}_{wj} = \underline{B}_{oj}\ (1-e_{Bj})$
6. $\underline{W}_{wj} = \underline{R}_{wj}\ w_{wj}$

CULTIVAR CALCULATIONS PROGRAM LISTING

Step	Key	Step	Key	Step	Key
1.	* LBL A	28.	÷	55.	- X - (w_{Bj})
2.	STO 9	29.	STO 3	56.	RCL 0
3.	↓	30.	R/S	57.	RCL 5
4.	STO 8	31.	* LBL B	58.	÷
5.	↓	32.	STO 0	59.	RCL 3
6.	STO 5	33.	- X - ($\underline{R}_{ej}$)	60.	÷
7.	↓	34.	↓	61.	- X - ($\underline{A}_{Bj}$)
8.	STO 7	35.	STO 4	62.	RCL 0
9.	1	36.	RCL 1	63.	RCL 3
10.	RCL 8	37.	- X - (w_{ej})	64.	÷
11.	RCL 9	38.	RCL 2	65.	- X - ($\underline{B}_{oj}$)
12.	÷	39.	- X - (w_{wj})	66.	STO 6
13.	-	40.	RCL 3	67.	RCL 4
14.	STO 1	41.	- X - (e_{Bj})	68.	X
15.	RCL 7	42.	RCL 4	69.	2
16.	RCL 8	43.	- X - (t_{Hj})	70.	÷
17.	-	44.	RCL 5	71.	- X - ($\underline{M}_{Bj}$)
18.	RCL 5	45.	- X - (P_j)	72.	1
19.	RCL 9	46.	RCL 1	73.	RCL 3
20.	-	47.	RCL 3	74.	-
21.	÷	48.	X	75.	RCL 6
22.	CHS	49.	1	76.	X
23.	1	50.	RCL 3	77.	- X - ($\underline{R}_{wj}$)
24.	+	51.	-	78.	RCL 2
25.	STO 2	52.	RCL 2	79.	X
26.	RCL 9	53.	X	80.	- X - ($\underline{W}_{wj}$)
27.	RCL 5	54.	+	81.	R/S

Appendix D

HP-67 PROGRAM FOR BREAKEVEN CALCULATION

Storage

Register	Parameter	Register	Parameter	Register	Parameter
I	N_p	6	M_{PSC}	2	$\underline{A}_B$
9	M_{fp}	5	M_H	1	M_{as}
8	T_r	4	$\underline{M}_{Bd}$	0	M_a
7	M_{TR}	3	$\underline{M}_B$		

Operating Instructions

			Notes
1.	Key in N_p	Press [ENT]	
2.	" " M_{TR}	" "	(kg)
3.	" " T_r	" "	
4.	" " M_{fp}	" [A]	
5.	" " $\underline{M}_B \cdot 10^{-3}$	" [ENT]	$(\underline{M}_B \cdot 10^{-3})$ = kg-person^{-1}
6.	" " $\underline{M}_{Bd} \cdot 10^{-3}$	" "	$(\underline{M}_{Bd} \cdot 10^{-3})$ = kg-person^{-1}
7.	" " M_H	" "	
8.	" " M_{PSC}	" [B]	
9.	" " M_a	" [ENT]	
10.	" " M_{as}	" "	
11.	" " $\underline{A}_B$	" [C]	

12. Read out:
- T_{BE} Breakeven time (years)
- M_{TP} Total PCELSS mass requirement (above resupply component mass)
- M_{wt} Water mass - transpiration reservoir
- M_{PS} Total growing environment equipment mass

To run again changing only a few parameter values:

key in new value, press STO X , where X is from above table. Repeat for each changed value

Press [GTO] [.] [0] [2] [5] [R/S]

CELSS BREAKEVEN ANALYSIS PROGRAM LISTING

```
1.  * LBL A
2.  STO 9
3.  ↓
4.  STO 8
5.  ↓
6.  STO 7
7.  ↓
8.  STO I
9.  R/S
10. * LBL B
11. STO 6
12. ↓
13. STO 5
14. ↓
15. STO 4
16. ↓
17. STO 3
18. R/S
19. * LBL C
20. STO 2
21. ↓
22. STO 1
23. ↓
24. STO 0
25. RCL I
26. RCL 2
27. X
28. ENT
29. ENT
30. RCL 0
31. X
32. X ⇄ Y
33. .
34. 6
35. Y^X
36. RCL 1
37. X
38. +
39. RCL 6
40. +
41. STO A
42. RCL I
43. RCL 8
44. X
45. RCL 4
46. X
47. 1
48. 0
49. X
50. STO B
51. RCL I
52. 1
53. 0
54. ÷
55. .
56. 4
57. 1
58. 5
59. Y^X
60. RCL 9
61. X
62. STO C
63. RCL 3
63a. RCL I
63b. X
64. +
65. RCL 5
66. +
67. RCL A
68. +
69. RCL B
70. +
71. STO D    (M_TP)
72. RCL 7
73. RCL I
74. X
75. ÷
76. - X -    (T_BE)
77. RCL D
78. - X -    (M_TP)
79. RCL B
80. - X -    (M_wt)
81. RCL A
82. - X -    (M_PS)
83. RTN
```

Calculations

1. $M_{PSS} = M_{as}(\underline{A}_B N_p)^{.6}$

2. $M_{PSU} = M_a \underline{A}_B N_p$

3. $M_{PS} = M_{PSS} + M_{PSU} + M_{PSC}$ (STO A)

4. $M_{wt} = 10 \cdot \underline{M}_{Bd} \cdot N_p \cdot T_r$ (STO B)

5. $M_{fp} = M_{fp} \left(\frac{N_p}{10}\right)^{.415}$ (STO C)

6. $M_B = N_p \cdot \underline{M}_B$

7. $M_{TP} = M_B + M_H + M_{FP} + M_{PS} + M_{wt}$ (STO D)

8. $T_{BE} = M_{TP} \div (\underline{M}_{TR} \cdot N_p)$

APPENDIX E

FORTRAN Program for Breakeven Calculation

Purpose: This program is based on the PRELIMINARY SCENARIO ANALYSIS MODEL by Robert M. Mason.

Author: Martha Sadler, New View, Sept 1980

Environment:
DEC VAX-11/780 VAX/VMS VAX-11 FORTRAN IV-PLUS

Non-Standard Code:
VAX-11 FORTRAN IV-PLUS extensions of ANS FORTRAN 1966:
- Data types: CHARACTER, LOGICAL*1,
- Block IF logical structure: IF THEN, ELSE, ELSE IF, ENDIF statements
- END= and ERR= in READ or WRITE statements
- OPEN, CLOSE, DEFINE FILE file control specifications

Commons Used:

<name>	<description>
REAL1	Real variables
CHAR2	Character variables
INT3	Integer variables
LOG4	Logical variables

Subroutines Called:

<name>	<description>
BLOCK DATA	COMMON DATA
PRODUC	This subroutine performs cultivar calculations.
BREAK	This subroutine performs breakeven calculations.
DESCRT	Gives description of variables when '?' input.
MFREIN	Modified version of FREEIN.FOR written by Walton
MDECDE	Modified version of DECODE.FOR written by Walton

Limitations
Exit Points
Constraints and Cautions

VARIABLE DESCRIPTIONS

TR	NUMBER OF DAYS OF TRANSPIRATION
MCONST	RATIO OF PLANT THAT IS DRY WEIGHT
TBDJ	TOTAL DRY BIOMASS(G PER SQ M PER DAY)
TBD	TOTAL DRY BIOMASS (G PER SQ M PER DAY)
TBFJ	TOTAL FRESH BIOMASS(G PER SQ M PER DAY)
TBF	TOTAL FRESH BIOMASS (G PER SQ M PER DAY)
EBDJ	EDIBLE DRY BIOMASS(G PER SQ M PER DAY)
EBD	EDIBLE DRY BIOMASS (G PER SQ M PER DAY)
EBFJ	EDIBLE FRESH BIOMASS(G PER SQ M PER DAY)
EBF	EDIBLE FRESH BIOMASS (G PER SQ M PER DAY)
WEJ	FRACTION OF WATER IN EDIBLE PORTION
MBD	DRY BIOMASS HOLDUP(G PER PERSON)
MPSC	MASS OF CONTROL EQUIPMENT FOR FOOD PRODUCTION MODULE(KG)
MA	MASS REQUIREMENT FOR GROWING AREA, UNSCALED COMPONENTS (KG PER SQ M)
MAS	MASS REQUIREMENT FOR GROWING AREA, SCALED COMPONENTS (KG PER SQ M)
MFP	FOOD PROCESSING EQUIPMENT MASS FOR 10 PERSONS(KG)
MH	MASS OF FOOD HARVESTING EQUIPMENT(KG)
WWJ	FRACTION OF WATER IN INEDIBLE PORTION
EBJ	EDIBLE FRACTION FRESH
PJ	TOTAL GROWTH RATE OF FRESH BIOMASS(G PER SQ M PER DAY)
WBJ	FRACTION OF WATER IN TOTAL BIOMASS
ABJ	GROWING AREA(SQ M PER PERSON)
REJ	PRODUCTION RATE OF FRESH EDIBLE FOOD (G PER PERSON PER DAY)
BOJ	TOTAL BIOMASS HARVEST RATE (G PER PERSON PER DAY)
THJ	TOTAL TIME TO HARVEST (DAYS)
TH	TOTAL TIME TO HARVEST (DAYS)
RWJ	HARVEST WASTE, FRESH (G PER PERSON PER DAY)
MBJ	TOTAL BIOMASS HOLDUP (G PER PERSON)
MB	TOTAL BIOMASS HOLDUP (G PER PERSON)
TOTMBJ	BIOMASS HOLDUP FOR TOTAL POPULATION
TOTMFP	FOOD PROCESSING EQUIPMENT MASS FOR TOTAL POPULATION (KG)
MTRJ	MASS REQUIRED FOR RESUPPLY/STORAGE OF FOOD J (KG PER PERSON PER YR)
MTP	ADDITIONAL MASS REQUIRED FOR ALTERNATIVE SCENARIO ABOVE THAT REQUIRED FOR BASELINE SCENARIO
MWT	MASS OF WATER REQUIRED FOR ADEQUATE HUMIDITY AND NUTRIENT RESERVOIR
MPS	TOTAL GROWING AREA EQUIPMENT MASS (KG)
NP	POPULATION
TBE	BREAKEVEN TIME (YEARS)

FORTRAN PROGRAM

```
C SEE 'PRELIMINARY SCENARIO ANALYSIS MODEL', CELSS WORKING PAPER,
C WP754-1 BY ROBERT MASON, APRIL,1980
      REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,
     X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
     XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
     X MTRJ,MTP,MWT,MPS,NP,TBE,ALLMBD,ALLMTR,ALLMBJ,ALLABJ
      CHARACTER*13 FDNAME(11),WHICH
      CHARACTER*80 LINE
      CHARACTER*6 VRNAME(6),GENAME(6),THIS
      LOGICAL*1 FINISH,COMBND,POPULN
      INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER,SAVE
      COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
     *TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
     *ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
      COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
      COMMON/LOG4/FINISH,COMBND,POPULN
      COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
C
      LAST =6
      SAVE = 12
      OMEGA = 11
      USER = 2
      DEFALT = 1
      TERMOT=6
      TERMIN=5
      FINISH = .FALSE.
      COMBND = .FALSE.
      POPULN = .FALSE.
C
      WRITE (TERMOT,5)
5     FORMAT (' ','THIS PROGRAM IS BASED
      X ON THE PRELIMINARY SCENARIO',/,
     X' ANALYSIS MODEL BY ROBERT M. MASON',//,
     X' TO OBTAIN A DESCRIPTION OF A VARIABLE, TYPE IN--?VARIABLE',/,
     X' NAME--WHEN INPUT IS ASKED FOR')
      OPEN(UNIT=10,NAME='MASON.DAT',TYPE='OLD')
9     WRITE (TERMOT,10)
10    FORMAT (' ','DO YOU WISH TO RUN A COMBINATION OF FOODS FOR',/,
     * ' BREAKEVEN ANALYSIS,1=YES,0=NO')
C
      READ (TERMIN,15) LINE
15    FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,9)
        ELSE
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,9)
        END IF
C
      IF (ANSR.EQ.1) THEN
```

```
C RUN COMBINATION
         COMBND = .TRUE.
         OPEN (UNIT=12,NAME='COMB.DAT',TYPE='NEW')
      END IF
C
20    CALL PRODUC
C
C IF A COMBINATION IS RUN, BREAKEVEN CALCULATIONS ARE MANDATORY
      IF (COMBND) THEN
         ANSR = 1
         GO TO 167
      END IF
C
159   WRITE (TERMOT,160)
160   FORMAT (' ','DO YOU WISH BREAKEVEN CALCULATIONS,1=YES,2=NO')
      READ (TERMIN,165) LINE
165   FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,159)
        ELSE
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,159)
        END IF
C
167   IF (ANSR.EQ.1) THEN
         WRITE (TERMOT,168)
168      FORMAT (' ','BREAKEVEN CALCULATIONS')
       IF (.NOT.POPULN) THEN
169     WRITE (TERMOT,170)
170     FORMAT (' ','ENTER POPULATION')
        READ (TERMIN,172) LINE
172     FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,169)
        ELSE
          MODE = 0
          CALL MFREIN (LINE,MODE,NP,NVAR,169)
        END IF
       END IF
C
      CALL BREAK
      WRITE (SAVE,200) FDNAME(FOOD),MTRJ,MBJ,MBD,ABJ
200   FORMAT (A11,F6.2,F7.3,F7.3,F6.2)
      END IF
C
      IF (.NOT.COMBND) THEN
C
599   WRITE (TERMOT,600)
600   FORMAT (' ','DO YOU WISH TO RUN THE PROGRAM AGAIN,1=YES,0=NO')
      READ (TERMIN,602) LINE
602   FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,599)
        ELSE
```

```
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,599)
        END IF
C
        IF (ANSR.EQ.1) THEN
          GO TO 20
        END IF
      ELSE
        POPULN = .TRUE.
605     WRITE (TERMOT,610)
610     FORMAT (' ','ANOTHER FOOD?,1=YES,0=NO')
      READ (TERMOT,615) LINE
615   FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,605)
        ELSE
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,605)
        END IF
C
625       IF (ANSR.EQ.0) THEN
          FINISH = .TRUE.
          ENDFILE SAVE
          CLOSE (UNIT=12)
          OPEN (UNIT=12,NAME='COMB.DAT',TYPE='OLD')
          ALLMBD = 0
          ALLMTR = 0
          ALLMBJ = 0
          ALLABJ = 0
690       READ (SAVE,700,END=710) MTRJ,MBJ,MBD,ABJ
700       FORMAT (11X,F6.2,F7.3,F7.3,F6.2)
          ALLMTR = ALLMTR + MTRJ
          ALLMBJ = ALLMBJ + MBJ
          ALLMBD = ALLMBD + MBD
          ALLABJ = ALLABJ + ABJ
          GO TO 690
C
710   FDNAME(FOOD) = 'DIET         '
      MBD = ALLMBD
      MTRJ = ALLMTR
      MBJ = ALLMBJ
      ABJ = ALLABJ
C
      WRITE (TERMOT,720)
720   FORMAT (' ','BREAKEVEN CALCULATIONS FOR DIET')
      CALL BREAK
C
         ELSE
           GO TO 20
         END IF
      END IF
      CLOSE (UNIT=10)
      CLOSE (UNIT=12)
      STOP
      END
C
```

```
C
      BLOCK DATA
      REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,
     X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
     XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
     X MTRJ,MTP,MWT,MPS,NP,TBE
      CHARACTER*13 FDNAME(11),WHICH
      CHARACTER*80 LINE
      CHARACTER*6 VRNAME(6),GENAME(6),THIS
      LOGICAL*1 FINISH,COMBND,POPULN
      INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
      COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
     *TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
     *ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
      COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
      COMMON/LOG4/FINISH,COMBND,POPULN
      COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
      DATA FDNAME/'DRY BEANS    ','PEANUT BUTTER','CABBAGE      ',
     X'CARROTS      ','TOMATOES     ','POTATOES     ','GREEN BEANS  ',
     X'LETTUCE      ','MELONS       ','PEAS         ','WHEAT        '/
      DATA GENVAR/1.,0,0,15.88,83.2,122.,0,0,0,0,0,0/
      DATA GENAME/'TR    ','MFP   ','MH    ','MPSC  ',
     X'MA    ','MAS   '/
      DATA VRNAME/'TH    ','TBD   ','TBF   ','EBD   ',
     X 'EBF   ','MCONST'/
      DATA DEFVAL/47.0,43.1,204.3,21.1,24.3,.217,
     X110.0,49.5,355.0,8.2,9.4,.139,30.0,10.4,180.8,9.9,172.1,.059,
     X80.1,43.6,315.6,21.3,154.2,.138,215,7.9,113.5,6.2,95.0,.073,
     X120.0,20.2,134.6,13.7,97.9,.150,60,108.9,920.6,26.3,305.2,.113,
     X28.0,11.6,221.1,8.5,161.3,.052,107.0,39.9,396.5,19.9,298.9,.083,
     X50.0,15.6,99.9,.6,3.7,.156,196.0,148.4,505.3,58.5,67.2,.294/
      END
C
C
      SUBROUTINE PRODUC
C THIS SUBROUTINE PERFORMS CULTIVAR CALCULATIONS
C
      REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,
     X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
     XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
     X MTRJ,MTP,MWT,MPS,NP,TBE
      CHARACTER*13 FDNAME(11),WHICH
      CHARACTER*80 LINE
      CHARACTER*6 VRNAME(6),GENAME(6),THIS
      LOGICAL*1 FINISH,COMBND,POPULN
      INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
      COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
     *TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
     *ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
      COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
      COMMON/LOG4/FINISH,COMBND,POPULN
      COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
C
9     WRITE(TERMOT,10)
10    FORMAT(' ','WOULD YOU LIKE A LIST OF FOODS STORED IN THE LIBRARY,
     X1=YES,0=NO')
      READ(TERMIN,20)LINE
```

```
20     FORMAT(A80)
         IF (LINE(1:1).EQ.'?') THEN
           CALL DESCRT (LINE,9)
         ELSE
           MODE = 1
           NVAR = 1
           CALL MFREIN(LINE,MODE,ANSR,NVAR,9)
         END IF
C
         IF (ANSR.EQ.1) THEN
           WRITE (TERMOT,30)  (FDNAME(I),I=1,OMEGA)
30         FORMAT(' ',A13)
         ENDIF
C
49     WRITE (TERMOT,50)
50     FORMAT (' ',/,' ENTER A SINGLE FOOD NAME')
       READ (TERMIN,55) LINE
55     FORMAT (A80)
C
         IF (LINE(1:1).EQ.'?') THEN
           CALL DESCRT (LINE,49)
         ELSE
           WHICH = LINE(1:13)
         END IF
C
       DO 57  I=1,OMEGA
           IF (WHICH.EQ.FDNAME(I)) THEN
             FOOD=I
             GO TO 35
           ENDIF
57     CONTINUE
C
       WRITE (TERMOT,60)
60     FORMAT (' ','FOOD NOT IN LIBRARY',/)
       GO TO 9
C
35     WRITE (TERMOT,40) WHICH
40     FORMAT (' ','WOULD YOU LIKE A LIST OF THE VARIABLES AND THEIR
      XDEFAULT VALUES FOR',/,' ',A13,' IN THE LIBRARY,ENTER 1 FOR YES,
      X0 FOR NO')
       READ (TERMIN,45) LINE
45     FORMAT (A80)
C
C IF ? THEN GETS DESCRIPTION OF VARIABLE
         IF (LINE(1:1).EQ.'?') THEN
           CALL DESCRT (LINE,35)
         ELSE
           MODE = 1
           NVAR = 1
C RETURNS ANSR
           CALL MFREIN (LINE,MODE,ANSR,NVAR,35)
         END IF
C
C
         IF (ANSR.EQ.1) THEN
C
70         DO 74 I=1,LAST
```

```
            WRITE (TERMOT,71)VRNAME(I),DEFVAL(I,FOOD)
71          FORMAT (' ',A6,4X,F5.1)
74        CONTINUE
C
      ENDIF
C
      DO 75 VAL = 1,LAST
      USRVAL(VAL,FOOD) = DEFVAL(VAL,FOOD)
75    CONTINUE
C
77    WRITE (TERMOT,80)
80    FORMAT (' ','WOULD YOU LIKE TO CHANGE A DEFAULT VALUE,1=YES,0
     X=NO')
      READ (TERMIN,85) LINE
85    FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,77)
        ELSE
          MODE = 1
          NVAR = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,77)
        END IF
C
C
      IF (ANSR.EQ.1) THEN
89      WRITE (TERMOT,90)
90      FORMAT (' ','WHICH VARIABLE?')
        READ (TERMIN,95) LINE
95      FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,89)
        ELSE
          THIS = LINE(1:6)
        END IF
C
98    WRITE (TERMOT,100)
100   FORMAT (' ','ENTER VALUE')
       READ (TERMIN,101) LINE
101    FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,98)
        ELSE
          MODE = 0
          CALL MFREIN (LINE,MODE,NUMBER,NVAR,98)
        END IF
C
        DO 110 I=1,OMEGA
          IF (THIS.EQ.VRNAME(I)) THEN
            USRVAL(I,FOOD)=NUMBER
            GO TO 77
          ENDIF
C
110     CONTINUE
C
```

```
C ERROR ROUTINE
          WRITE (TERMOT,115)
115       FORMAT (' ','VARIABLE NOT IN FILE')
          GO TO 35
        ENDIF
C
C VARIABLES SET TO DEFAULT OR USER DEFINED VALUES
        THJ=USRVAL(1,FOOD)
        TBDJ=USRVAL(2,FOOD)
        TBFJ=USRVAL(3,FOOD)
        EBDJ=USRVAL(4,FOOD)
        EBFJ=USRVAL(5,FOOD)
        MCONST = USRVAL(6,FOOD)
C
139     WRITE (TERMOT,140),FDNAME(FOOD)
140     FORMAT (' ','TO RUN PROGRAM ENTER DAILY REQUIRMENT OF ',A13,/,
       X' IN GRAMS')
        READ (TERMIN,141) LINE
141     FORMAT (A80)
C
          IF (LINE(1:1).EQ.'?') THEN
            CALL DESCRT(LINE,139)
          ELSE
            MODE = 0
            CALL MFREIN(LINE,MODE,AMOUNT,NVAR,139)
          ENDIF
C
C EQUASIONS FOR CALCULATIONS
        REJ = AMOUNT
        WEJ = 1 - EBDJ / EBFJ
        WWJ = 1 - ((TBDJ - EBDJ) / (TBFJ - EBFJ))
        EBJ = EBFJ / TBFJ
        PJ = TBFJ
        WBJ = WEJ * EBJ + WWJ * (1-EBJ)
        ABJ = REJ / (PJ * EBJ)
        BOJ = REJ / EBJ
        MBJ = (BOJ * THJ / 2) / 1000.
        RWJ = BOJ * (1-EBJ)
        HARWWJ = RWJ * WWJ
C
        WRITE (TERMOT,145)
145     FORMAT (' ','FOOD',10X,'REJ',5X,'TH',
       X 4X,'TBDJ',3X,'TBFJ',3X,'EBDJ',
       X3X,'EBFJ',3X,'EBJ',3X,'BOJ',5X,'ABJ',3X,'WEJ')
        WRITE(TERMOT,150) FDNAME(FOOD),REJ,THJ,TBDJ,
       X TBFJ,EBDJ,EBFJ,EBJ,BOJ
       X,ABJ,WEJ
150     FORMAT (' ',A13,F5.1,2X,F5.0,2X,4(F5.1,2X),F4.3,1X,F7.1,
       X1X,F6.2,1X,F4.3)
C
        RETURN
        END
C
C
C
        SUBROUTINE BREAK
C THIS SUBROUTINE PERFORMS BREAKEVEN CALCULATIONS
```

```
C
      REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,
     X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
     XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
     X MTRJ,MTP,MWT,MPS,NP,TBE
      CHARACTER*13 FDNAME(11),WHICH
      CHARACTER*80 LINE
      CHARACTER*6 VRNAME(6),GENAME(6),THIS
      LOGICAL*1 FINISH,COMBND,POPULN
      INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
      COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
     *TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
     *ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
      COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
      COMMON/LOG4/FINISH,COMBND,POPULN
      COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFALT,USER
C
179   WRITE (TERMOT,180)
180   FORMAT(' ','DO YOU WISH A LIST OF VARIABLES AND DEFAULT VALUES,
     X0=NO,1=YES')
      READ (TERMIN,185) LINE
185   FORMAT(A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,179)
        ELSE
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,179)
        END IF
C
        IF (ANSR.EQ.1) THEN
          DO 210 I=1,LAST
            WRITE (TERMOT,195) GENAME(I),GENVAR(I,DEFALT)
195         FORMAT (' ',A6,3X,F6.2)
210        CONTINUE
        ENDIF
C
C SETS DEFAULT VALUES TO USER VALUES
      DO 220 I=1,LAST
        GENVAR(I,USER)=GENVAR(I,DEFALT)
220   CONTINUE
C
225   WRITE (TERMOT,230)
230   FORMAT(' ','DO YOU WISH TO CHANGE THE VALUE OF A VARIABLE,
     X1=YES,0=NO')
      READ (TERMOT,240) LINE
240   FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,225)
        ELSE
          MODE = 1
          CALL MFREIN (LINE,MODE,ANSR,NVAR,225)
        END IF
C
        IF (ANSR.EQ.1) THEN
249       WRITE (TERMOT,250)
```

```
250       FORMAT (' ','WHICH VARIABLE')
          READ (TERMIN,260) LINE
260       FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,249)
        ELSE
          THIS = LINE(1:6)
        END IF
C
269       WRITE (TERMOT,270)
270       FORMAT(' ','ENTER VALUE')
          READ (TERMIN,272) LINE
272       FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
          CALL DESCRT (LINE,269)
        ELSE
          MODE = 0
          CALL MFREIN (LINE,MODE,NUMBER,NVAR,269)
        END IF
C
          DO 280 I=1,LAST
            IF(THIS.EQ.GENAME(I)) THEN
              GENVAR(I,USER)=NUMBER
              GO TO 225
            ENDIF
280       CONTINUE
C
          WRITE (TERMOT,285)
285       FORMAT (' ','VARIABLE NOT IN FILE')
          GO TO 179
        ENDIF
C
C SETS VARIABLES EQUAL TO USER VALUES
      TR = GENVAR(1,USER)
      MFP = GENVAR(2,USER)
      MH = GENVAR(3,USER)
      MPSC = GENVAR(4,USER)
      MA = GENVAR(5,USER)
      MAS = GENVAR(6,USER)
C
C IF THE PLANT COMBINATION IS NOT COMPLETED
      IF (.NOT.FINISH) THEN
        MBD = MBJ * MCONST
        MTRJ = (EBDJ * 365.25 * 1.53 * ABJ) /1000.
      END IF
C
C EQUASIONS FOR BREAKEVEN CALCULATIONS
      MPS = (MPSC) + (MAS * (ABJ * NP) ** .6) + (MA * ABJ * NP)
      MWT = 10. * MBD * NP * TR
      TOTMFP = MFP * (NP /10.) ** .415
      TOTMB = NP * MBJ
      MTP = TOTMB + MH + TOTMFP + MPS + MWT
      TBE = MTP / (MTRJ * NP)
C
      WRITE (TERMOT,290)
```

```
290    FORMAT (' ',3X,'FOOD',28X,'MTRJ',5X,'MB',8X,'MPS',8X,'MWT',6X,
      X'TBE',/)
       WRITE (TERMOT,200) FDNAME(FOOD),MTRJ,MBJ,MPS,MWT,TBE
200    FORMAT (' ',3X,A13,18X,F6.2,2X,F7.3,2X,F8.1,2X,F8.1,2X,F7.1,/)
C
       RETURN
       END
C
       SUBROUTINE DESCRT(LINE,*)
C THIS SUBROUTINE RETURNS THE DESCRIPTION OF ANY VARIABLE WHEN A '?'
C VARIABLE NAME IS ENTERED
C
       CHARACTER*80 LINE
       CHARACTER*90 RECORD
       CHARACTER*6 VARBLE
       CHARACTER*83 SCRIPT
       INTEGER FILE,TERMOT
C
       FILE = 10
       TERMOT = 6
C
C READS THE FILE THAT CONTAINS DESCRIPTIONS
5      READ (FILE,10,END=25) VARBLE,SCRIPT
10     FORMAT (A6,1X,A83)
C
C COMPARES WITH FILE TO FIND DESCRIPTION
         IF (LINE(2:7).EQ.VARBLE) THEN
           WRITE (TERMOT,15) VARBLE,SCRIPT
15         FORMAT (' ',A6,3X,A83)
           GO TO 40
C
C READS ANOTHER
         ELSE
           GO TO 5
C
         END IF
C
C ERROR ROUTINE
25     WRITE (TERMOT,30)
30     FORMAT (' ','DESCRIPTION OF VARIABLE NOT FOUND')
C
C SETS POINTER AT BEGINNING OF FILE
40     REWIND FILE
       RETURN1
       END
```

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16. Abstract
This report considers a model of the relative mass requirements of food production components in a controlled ecological life support system (CELSS) based on regenerative concepts. Included are a discussion of model scope, structure, and example calculations. The report is intended to serve as a working paper which can provide a basis for further model development and analysis. Computer programs for cultivar and breakeven calculations are included.

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