HYMNS

Hury Yield Model and ecoNomic Synthesis

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Hury Yield Model (HYM)

1. Introduction

The Hury Yield Model and economic Synthesis (HYMNS) contains a whole stand model constructed to provide rough estimates of biomass and pit prop production in Sind "huries". A "hury" is a block plantation of *Acacia nilotica* that is grown along the plains of the River Indus in Pakistan (Sangi 1987). Apparently the practice of growing huries has been limited to small private landowners in Sind Province around Hyderabad (Sangi 1987, Sheikh 1986).

The province of Sind has an arid/dry subtropical climate. The summers are very hot (temperatures of 115° to 120° F are common) while winters are cool in the north and mild in the south. The average annual precipitation is 175 mm, is very irregular, and is received mostly during the monsoon season (during the months of June through August). Physiographically, the province has three distinct regions: 1) the rocky hills in the west; 2) sandy desert in the east; and 3) alluvial plains in the center. These plains are the result of deposition of silt by the Indus River. The river is in the mature stage and constitutes the lower portion of the famous valley of Indus, considered to be the cradle of civilization. The soil is fertile and sustains rich agricultural crops under irrigation.

An array of forest products are derived from *Acacia nilotica* in this part of Pakistan. Pieces larger than those typically grown in huries are sawn into furniture and construction lumber, and logs between 6.5 and 17.0 cm in diameter are consumed in large numbers by the mining industry in both Sind and Baluchistan provinces. Smaller woody material is a major source of fuelwood, while foliage, bark, seed pods and smaller twigs form a major component of goat fodder. Occasionally, the exuded gum is sold as gum arabic, and in some locales lac is cultivated on *Acacia nilotica*. Also, in the vicinity of tanneries bark is gathered for tannin extraction. and in some locations nectar from *Acacia* blossoms form the basis for significant honey production.

Indirect benefits of hury cultivation, especially in the context of farm forestry, include soil enrichment by nitrogen fixation and addition of organic matter. The benefits of hury cultivation, along with both a description of the practice and an assessment of its biomass productivity, have been previously discussed (Sangi 1987). The current project was initiated under contract from USAID/Winrock to compile hury yield data into a stand level model for the IBM PC/XT/AT microcomputer, thereby providing a tool to assess productivity and to explore various management alternatives. The objective of the study was *not* an

inventory of *Acacia* volume or biomass in Sind huries, but rather a characterization of the economic and biological productivity of huries under a range of stand density management regimes.

2. *Data*

The two major tasks in preparing a data base for model construction were field data collection and computer input and compilation.

2.a. *Field data collection procedures*

Hury data were collected over a six week period in the autumn of 1987. With respect to the Hury Yield Model, the two major phases of data collection were: 1) plot measurement; and 2) biomass sampling. The third phase of field data collection involved landowner interviews during which various economic and operational data were compiled. This latter procedure will be described in the economic report since the only piece of data applied to yield model development from this phase was the date of *Acacia* sowing.

2.a.i. *Plot measurement*

Sampled huries were selected by Sind Forest Department personnel on a daily basis. Initially huries were selected randomly while travelling through the areas just south of Khyber Village and north to Hala and Saeedabad. Later in the study huries were deliberately chosen to meet certain age and stand density criteria defining gaps in the data base. Since manipulation of stand density will be the primary cultural tool in hury management, an attempt was made to sample the full range in stand density over each age of interest. The final distribution of huries by age and density is illustrated in Table 1. Once a hury was selected, the following steps were followed to facilitate stand characterization:

1) The hury was visually stratified during an initial walkthrough according to apparent cultural or irrigation history as suggested by differences in:
- stand density
- average diameter
- average height
- amount and vigor of foliage
- pruning height

To qualify as a distinct stratum, the target area must have covered at least 100 m^2 (0.01 ha, 10 x 10 m, or 5.6 m radius).

2) Within a stratum, a starting point was chosen, then a set of random numbers was selected from a random number table. The first and second number corresponded to the number of paces (pace = two steps) counted perpendicular and parallel, respectively, to the nearest hury edge. If this procedure brought the point outside or on the edge of the target stratum, a new starting point was chosen and the procedure was repeated. If the identified stratum was just 100 m^2 or close to it, the plot

Table 1. Distribution of plots by hury density and age.

Stems per Hectare	Age 1	2	3	4	5	6	7	Sub Total
2,000		3	1		1	1		6
2,001- 4,000		2	3	3	4	3	2	17
4,001- 6,000		3	4	4	2			13
6,001- 8,000		4	3	5	1	1		14
8,001-10,000		1			1	1		3
10,001-12,000	1			1				2
12,001-14,000			2					2
14,001-16,000			1					1
16,001-18,000								
18,001-20,000			1					1
>20,000	5		1					6
Subtotal	6	13	16	13	9	6	2	65

center was located as close to the center of the stratum as could be approximated.

3) The new plot was assigned a two part identifier consisting of an assigned hury number and consecutively plot numbers. For example, plot 9-3 was the third plot in hury 9.

4) Plot size varied by hury age, or more specifically, by stand density. In one- or two-yr-old huries, a 1/500 ha plot was used if this allowed a sample size of at least 50 trees. Furthermore, areas that were broadcast sowed were sampled with a circular plot of radius 2.52 m, and areas that were row sowed were sampled with a semicircular plot of radius 3.57 m with the long axis oriented perpendicular to the rows. All older or sparser huries were sampled with circular 1/250 ha plots (radius = 3.57 m), except for very sparsely stocked stands. If less that 10-15 stems were expected per 1/250 ha plot, a 1/100 ha plot was established instead (radius = 5.64 m). Once the plot center was located, the live stems within the plot were numbered with white chalk, except for very small stems in the youngest huries. Stems that represented different forks of the same tree were given the same stem number. Dead stems were assigned "M" instead of a tree number.

5) All live and dead stems taller that 1.3 m were measured for dbh at 1.3 m with either a diameter tape (≥2 cm) or calipers (<2 cm), to the nearest 0.1 cm. One exception was plot 10-1, in which only tree heights were recorded due to the large number of stems under or only slightly above 1.3 m.

6) All live and dead trees were measured for height, to the nearest 0.1 m. If the trees were < 4 m tall, the height and height to the lowest live branch (on live trees) were read directly with a 3 m height pole graduated in 0.1 m units. Trees > 4 m tall were measured by the pole-tangent method (Curtis and Bruce 1968). In this technique, the 3 m height pole was stood up straight with its base at the base of the tree. The mensurationist then moved away from the tree, perpendicular to any lean or sag, to a spot from which he could easily see the tip of the tree as well as the base and top of the height pole. The following clinometer readings were then recorded:

- angle to base of the pole, nearest 0.5 degree
- angle to top of the pole, nearest 0.5 degree
- angle to the tree top, nearest 0.5 degree
- on live trees, angle to lowest live branch, nearest 0.5 degree

Trees with a slight lean or sag were visually stood completely upright to estimate height and angle readings. If sag or lean was severe, the height pole was stood upright exactly beneath the tip of the tree, as projected by a 90-degree sighting (by clinometer) on the tree tip. The distance from the center of the tree base to the height pole was recorded to the nearest 0.1 m,

and the above angles were likewise recorded.

Since plots 5-1 and 13-1 were quite dense, tree heights were taken only on one half of each plot.

7) Any cut stumps within the plot were measured for diameter outside bark at 2 cm from ground level, to the nearest 0.1 cm. The stumps were designated by an "S" on the field data sheets (Appendix A).

2.a.ii. Pruning measurements

A pair of two-yr-old plots was selected for pruned branch measurements - the first was from a low density hury and second was from a high density hury, both of which had received the apparently typical second year pruning. On the low density plot all branch stubs 3 mm and greater in basal diameter were measured by calipers, up to a height of approximately 2.5 m, the average pruning height. On the high density plot all branch stub diameters were similarly recorded, but only on trees in one half of the plot.

2.a.iii. Biomass sampling

A total of 31 biomass trees was sampled from five huries ranging in age from one yr to six yrs (Table 2). Within a hury, trees were sampled by choosing across the full range in diameters present. At the very least, the smallest and largest diameters in a given hury were targeted. Sample tree distribution by age and dbh is shown in Table 2. The following measurements were taken on all trees sampled:

- Stump diameter 2 cm above ground level, to the nearest 0.1 cm
- Dbh to the nearest 0.1 cm
- Height of the standing tree by the pole-tangent or direct read method, to the nearest 0.1 m
- Height of the felled tree to the nearest 0.1 cm
- Fresh weight of the following fractions of the tree:
  - foliage and woody material < 2.0 cm in diameter outside bark (dob)
  - woody material between 2.0 and 6.5 cm dob, except for pieces designated as "pit props" by the laborers
  - each individual pit prop, usually corresponding to material between 6.5 and 17.0 cm dob
- On a random sample of branches between 0 and 2.0 cm in basal diameter, fresh weight of the following fractions:
  - total foliage + woody material
  - total woody material after all potential fodder (leaves + succulent twigs) had been clipped off
- Small end dob (nearest 0.1 cm), large end dob (nearest 0.1 cm), and total length (nearest 0.01 m) of all pit props.

Larger trees and pieces were weighed with a 50-kg spring scale

Table 2. Distribution of biomass samples by dbh and age.

DBH (cm)	Age 1	2	3	4	5	6	7	Sub Total
0 - 1.9	3							3
2 - 3.9	2	2	2		1			7
4 - 5.9	1	1	1		2	1		6
6 - 7.9			2		1	1		4
8 - 9.9			1			4		5
10 - 11.9					2	1		3
12 - 13.9						1		1
14 - 15.9					1	1		2
Subtotal	6	3	6		7	9		31

graduated in units of 0.5 kg, and smaller trees and materials were weighed with a 2.5-kg spring scale graduated in units of 0.050 g.

2.b. Data compilation

Field data consisted of some measurements, such as angle to the tree top, that have to be converted into dimensions useful to tree and stand level modeling. The data then require some degree of editing to ensure that no gross errors were propogated.

2.b.i. Computation of heights

All angle readings on tree heights and heights to first live branch were converted to height from ground level by applying various trigonometric formulae (Curtis and Bruce 1968). If the tree was not leaning severely, heights were computed as

$$HT = P\ [(\tan TT - \tan PB) / (\tan PT - \tan PB)]$$

where HT = total height in m
P = height of pole in m
TT = angle to top of the tree
PB = angle to the pole base (tree base)
PT = angle to top of pole

On leaning trees, the vertical height to the top of the tree as it stands is first computed by the above formula,

$$HL = P\ [(\tan TT - \tan PB) / (\tan PT - \tan PB)]$$

where HL = height to top of leaning tree in m

The Pythagorean theorem then is invoked to compute

$$HT = \sqrt{[HL^2 + D^2]}$$

where HT = total height in m
D = ground distance from tree base to vertical projection of tree top

2.b.ii. Estimation of tree heights on subsampled plots

On those plots containing only a subsample of tree heights, the heights of all remaining trees were estimated from a height-diameter curve constructed from the subsample of live trees. The two resulting height-diameter curves were

Plot 5-1: $HT = 1.3 + \exp[a_1 - a_2 D^{a_3}]$

a_1 = 1.94549 (0.474117)
a_2 = -1.41227 (0.425292)
a_3 = -0.782514 (0.473547)
$S_{y.x}$ = 0.6210
R^2 = 0.652

Plot 13-1: $HT = 1.3 + \exp[b_1 - b_2 D^{b_3}]$

b_1 = 2.68086 (0.524230)
b_2 = -2.20820 (0.549771)
b_3 = -0.473372 (0.129852)
$S_{y.x}$ = 0.4121
R^2 = 0.640

Both equations were fit in nonlinear form since a modified likelihood criterion (Furnival 1961) indicated that the logarithmically transformed model was less appropriate. With a logarithmic model Furnival's index was 0.6835 and 0.5119 for plots 5-1 and 13-1, respectively, vs. 0.6210 and 0.4121 for the nonlinear models (the lower the index, the better the fit). Weighting did not improve the nonlinear models.

2.b.iii. Estimation of dbh on Plot 10-1

Since trees on Plot 10-1 were just approaching breast height (1.3 m), they were measured only for height. Diameters were predicted by compiling a data base consisting of all live trees that were measured for both height and dbh, but that were also less than 4.0 m in total height. Numerous models were fit to these data. The following model appeared best:

$$D = c_1 (H-1.3)^{c_2} + c_3 SPH$$

where D = diameter at breast height (1.3 m) in cm
H = total tree height in m
SPH = number of stems per hectare/100

c_1 = 0.833439 (0.0154944)
c_2 = 1.04299 (0.0593019)
c_3 = -0.000667568 (0.000146488)

The optimal weighting factor was H^{-2} as illustrated by the following indices of fit (Furnival 1961):

Weight	Furnival's index
1	0.4222
H^{-1}	0.3409
H^{-2}	0.3123
H^{-3}	0.3432

Diameter of all trees on Plot 10-1 with heights greater than 1.3 m were estimated with this equation using both the height of the subject tree and the average stand density (SPH).

2.b.iv. Data editing

An initial level of data editing was performed each day after field work. At this time, all tree heights were computed from the appropriate trigonometric formula on a programmable calculator. Obvious errors in heights were signaled by large departures from the general height-diameter relationship. In almost all cases, gross errors could be traced back to an obvious recording error, such as recording height angles for a large tree under and adjacent small tree, and vice versa.

After all data were entered into the computer, including the computed heights, two basic checks were made. First, a program was written to compile the data pertinent to analysis into a model building data base. At this time heights were recomputed and compared to the hand calculated values. If any discrepancies occurred, the correpsonding plot and tree were flagged. This resulted in identification of several data entry errors, which were then corrected by retrieving the correct value from the field sheets.

After this initial phase of constructing a modeling data base was completed, height-diameter plots were produced for each individual plot. Gross aberrations were investigated, and if they were attributable to either a data entry error or an obvious recording error, they were corrected.

3. Model components

The Hury Yield Model is structured around four major components: 1) individual tree biomass equations; 2) a set of site curves or cumulative height growth curves; 3) a maximum size-density relationship; and 4) a yield function for total above-ground *Acacia* biomass. Construction of individual tree biomass equations was an essential modeling phase which allowed subsequent estimation of per acre yields, by product classes, for the 65 individual sample plots.

3.a. Biomass equations

Three different type of biomass equations were developed, all of which are based on green or fresh weight.

3.a.i. Total tree biomass by component

As an initial screening, various equation forms were fit to the total biomass data (all components summed). A set of linear,

logarithmic, and nonlinear models was fit, applying various weighting factors to correct for nonconstant variance. The equations were then compared by Mallow's C_p (Draper and Smith 1981) and by a modified likelihood criterion (Furnival 1961) to choose the model providing the closest fit to the data and the best conformity to regression assumptions (see Draper and Smith 1981). By the latter criterion, the best model will exhibit the lowest Furnival's (1961) index. As shown in Table 3, the following model performed most favorably (with a weighting factor of $(D^2H)^{-1.6}$):

[1] $$B = b_0 + b_1 D^2 H + b_2 H^2$$

where B = predicted total above-ground biomass (kg)
D = diameter (cm) at breast height (1.3 m)
H = total height (m)
b_0, b_1, b_2 = regression parameters estimated from the data

b_0 = 0.620993
b_1 = 0.0364857 (0.0017451)
b_2 = -0.0338364 (0.0061298)

The coefficient of multiple determination (R^2) on the transformed scale was 0.993 for this equation.

Since this model performed optimally for total above-ground biomass, this same form was retained for fitting component equations. A procedure presented by Cunia and Briggs (1984) was followed for forcing additivity of biomass components (that is, the sum of the predictions from the three component equations will always equal the prediction from the total biomass equation). This model can be explained by considering three initial predictor variables $x_1=1$, $x_2=D^2H$, $x_3=H^2$. The objective is to estimate four biomass components: 1) material < 2.0 cm in diameter; 2) material between 2.0 and 6.5 cm; 3) material between 6.5 cm and 17.0 cm; and 4) total.

Table 3. Comparison of equations for predicting total above-ground biomass.

Model	Weight	Furnival's index
Linear		
$B = b_0 + b_1 D^2$	$(D^2 H)^{-1}$	6.110
$B = b_0 + b_1 D^2 H$	$(D^2 H)^{-1}$	2.468
	$(D^2 H)^{-1.5}$	
	$(D^2 H)^{-2}$	3.961
	$(D^2 H)^{-3}$	
$B = b_0 + b_1 D^2 H + b_2 H$	$(D^2 H)^{-1}$	2.152
$B = b_0 + b_1 D^2 H + b_2 H^2$	$(D^2 H)^{-1}$	2.101
	$(D^2 H)^{-1.5}$	1.804
	$(D^2 H)^{-2}$	3.961
	$(D^2 H)^{-3}$	4.629
Nonlinear		
$B = b_0 + b_1 D^{b_2} H^{b_3}$	1	3.760
	$(D^2 H)^{-0.5}$	2.677
	$(D^2 H)^{-1}$	2.590
	$(D^2 H)^{-1.5}$	9.030
$B = b_1 D^{b_2} H^{b_3}$	1	3.820
	$(D^2 H)^{-0.5}$	2.795
	$(D^2 H)^{-1}$	3.091
	$(D^2 H)^{-2}$	12.006
Logarithmic		
$\log B = b_0 + b_1 \log D$	1	7.371
$\log B = b_0 + b_1 \log H$	1	13.413
$\log B = b_0 + b_1 \log D + b_2 \log H$	1	7.310

Therefore, define variables

x_{i1} = 1 if the observation is on component i
0 otherwise

x_{i2} = D^2H if the observation is on component i
0 otherwise

x_{i3} = H^2 if the observation is on component i
0 otherwise

where i = 1, 2, 3, or 4, corresponding to the above biomass fractions

The regression model then becomes

$$[2] \quad B = \sum_{i=1}^{4} \sum_{j=1}^{3} \beta_{ij} x_{ij}$$

subject to the constraints that

$$\beta_{13} = 0$$

and

$$\beta_{11} + \beta_{21} + \beta_{31} = \beta_{41}$$

$$\beta_{12} + \beta_{22} + \beta_{32} = \beta_{42}$$

$$\beta_{13} + \beta_{23} + \beta_{33} = \beta_{43}$$

The full model was fit first, with each component equation containing both the D^2H and H^2 terms; however, the H^2 term was not significantly different from zero for the fine fraction (< 2 cm). This term was therefore dropped from the model and two series of fits performed with various weighting factors. The first series allowed a nonzero intercept, and the second series was forced through the origin since biomass should equal zero at zero height and diameter. As shown in Table 4, the model with a nonzero intercept and weighting factor of $(D^2H)^{-1}$ had the lowest Funival's index, and hence the best fit to the biomass data. The implied biomass equations are as follow:

[3] $$B(1) = \underset{(.07760)}{0.540308} + \underset{(.00094)}{0.025356}\, D^2H$$

[4] $$B(2) = \underset{(.09086)}{-0.257281} + \underset{(.00137)}{0.017957}\, D^2H + \underset{(.00835)}{0.058958}\, H^2$$

[5] $$B(3) = \underset{(.09086)}{0.336169} + \underset{(.00137)}{0.043021}\, D^2H - \underset{(.00835)}{0.091873}\, H^2$$

[6] $$B(T) = \underset{(.09086)}{0.619187} + \underset{(.00137)}{0.086334}\, D^2H - \underset{(.00835)}{0.032915}\, H^2$$

where
- B(1) = predicted kg of biomass in fine fraction (< 2.0 cm)
- B(2) = predicted kg of biomass in firewood fraction (between 2.0 and 6.5 cm)
- B(3) = predicted kg of biomass in pit prop fraction (between 6.5 and 17.0 cm)
- B(T) = predicted kg of total biomass of all fractions summed
- D = tree diameter in cm at 1.3 m from ground
- H = total tree height in m

3.a.ii. Prediction of forage biomass from branch diameter

An equation for predicting forage biomass (foliage + succulent twigs) from branch diameter was developed from the 27 branches subsampled for forage. Numerous weighted and unweighted linear and nonlinear models were tested for their performance, as illustrated in Table 5. The quadratic model and nonlinear model, both with a weight of branch diameter raised to a power of five, had the best indices of fit. Since these models produced nearly an equivalent fit, the nonlinear model was selected since it extrapolated to a prediction of zero when branch diameter equals zero:

[7] $$FB = \underset{(.003663)}{0.0495245}\, BD^{\underset{(.13494)}{2.69834}}$$

where
- FB = forage biomass in kg
- BD = branch diameter in cm

Table 4. Comparison of forced-additivity biomass equations.

Model	Weight	Furnival's index
[2] with nonzero intercept	1	
	$(D^2H)^{-0.5}$	2.579
	$(D^2H)^{-1.0}$	2.181
	$(D^2H)^{-1.5}$	2.292
	$(D^2H)^{-2.0}$	2.500
[2] with zero intercept	1	3.580
	$(D^2H)^{-0.5}$	2.634
	$(D^2H)^{-1.0}$	2.866
	$(D^2H)^{-1.5}$	7.482

3.a.iii. *Forage proportion in fine fraction*

A double sampling strategy was also implemented to provide an estimate of the proportion of the fine biomass fraction that represented forage (foliage + succulent twigs). As outlined in the description of field data collection, a subsample of 2.0 cm branches was weighed for total biomass and total woody biomass. The forage biomass was therefore expressed as a function of total biomass for material of this size class,

[8] $FB = b_1 TB$

where FB = predicted kg of forage biomass
TB = kg of total biomass of 2.0 cm branch

Various weights were applied during estimation of the regression parameter, as shown in Table 6; however, the unweighted estimator proved best. The equation applied in the Hury Yield Model was, therefore,

[9] $FB = 0.30369\ TB$
(.02362)

Table 5. Equations for predicting forage biomass from branch diameter.

Model	Weight	Furnival's index
$FB = b_0 + b_1 BD$	1	0.0642
$FB = b_0 + b_1 BD + b_2 BD^2$	1	0.0613
	BD^{-1}	0.0492
	BD^{-2}	0.0400
	BD^{-3}	0.0334
	BD^{-4}	0.0294
	BD^{-5}	0.0280
	BD^{-6}	0.0293
$FB = b_1 BD^{b_2}$	1	0.0601
	BD^{-2}	0.0395
	BD^{-3}	0.0332
	BD^{-4}	0.0296
	BD^{-5}	0.0288
	BD^{-6}	0.0312

Table 6. Forage biomass prediction equations.

Model	Weight	Furnival's index
$FB = b_0 + b_1 TB$	1	0.0805
$FB = b_1 TB$	1	0.0778
	TB^{-1}	0.0796
	TB^{-2}	0.0818
	TB^{-3}	0.0847

3.b. Site curves

For want of a more appropriate index of site productivity, such as one involving irrigation frequency, the site index approach was adopted. The first step in applying the site index concept was to define explicitly the "height" used in both construction of site curves and determination of site index. Given the strictly cross-sectional nature of the data, a guide curve technique remained the only option for construction of site index equations. These site index equations defined the expected height growth trajectory of the stand component used in site curve construction.

3.b.i. Definition of top height

The site curves were designed to mimic the cumulative height growth of the five largest stems per plot by dbh. Since an objective was to obtain 15-20 stems per plot, an equivalent statement would be that the site curves describe the cumulative height growth of the five largest stems (by dbh) out of a cluster of 20 stems. On average this would also represent approximately the largest 1200 stems per hectare. The height of this component will be referred to as the *top height* of the hury or hury stratum.

3.b.ii. Construction of site index equations

The site curve construction technique was limited by the fact that only cross-sectonal data were available from the temporary plots; hence, techniques employing time series data either from stem sectioning or repeat measurements were inappropriate. Instead a guide curve was fit through the entire data set, consisting of five trees from each of 65 plots. The curve took the form of a Chapman-Richards growth equation,

$$TH = O_1 [1 - \exp(O_2 A)]^{O_3}$$

where TH = top height of the plot in m
A = age of the hury in months

The resulting regression equation was

$$[10] \quad TH = d_1 [1 - \exp(d_2 A)]^{d_3}$$

with d_1 = 11.2016 (0.285259)
d_2 = -0.0564826 (0.00853996)
d_1 = 1.75952 (0.375256)

A five-year or 60-month base age was selected to index the site curves. The individual site curves could therefore be derived by assuming that parameters O_2 and O_3 are constant among sites, then solving for the asymptote O_1 that yields the correct top height

at age 60 months. Since the top height equation for a hury with site index S should produce S at base age A_0, it should be true that

$$S = d_1 [1 - \exp(d_2 A_0)]^{d_3}$$

Solving for d_1,

$$d_1 = S [1 - \exp(d_2 A_0)]^{d_3}$$

Substituting for d_1 in the regression equation,

$$TH = S \left| \frac{[1 - \exp(d_2 A)]}{[1 - \exp(d_2 A_0)]} \right|^{d_3}$$

and similarly,

$$S = TH \left| \frac{[1 - \exp(d_2 A_0)]}{[1 - \exp(d_2 A)]} \right|^{d_3}$$

For the parameter estimates given above, the top height equation becomes

$$TH = 1.062259\ S\ [1 - \exp(-0.0564826\ A)]^{1.75952}$$

The cumulative top height curves for site indices 5 through 15, in increments of 2 m, are illustrated in Appendix A.1.

3.c. Maximum size-density relationship

Mortality estimates from the Hury Yield Model will be crude, at best. Since a solid data base of repeated observations on permanent or semi-permanent plots was not available, the mortality component relies heavily on current biological theory and subjective judgement as to how the huries behave. All mortality trees were measured on the plots and all cut stumps tallied as well; however, the full plot history and time interval over which the mortality occurred is unknown. Therefore, these mortality and stump data only helped to guide the construction of reasonable mortality functions. The maximum size-density relationship inherent in numerous stand density management diagrams (Reineke 1933, Gingrich 1967, Drew and Flewelling 1981) forms the foundation for the hypothesized hury mortality model.

3.c.i. Maximum size-density line

Reineke (1933) developed a diagram of stand density in which he plotted number of stems per acre on quadratic mean plot diameter. When both axes were on a logarithmic scale, the plots fell along a line described by

$$\ln TPA = b_0 + b_1 \ln D_q$$

where ln = natural logarithm function
TPA = number of trees per acre
D_q = quadratic mean diameter

Numerous species were found to exhibit a slope (b_1) of approximately -1.605. Later Japanese work and its subsequent application to forestry resulted in stand density models that hypothesized a maximum size-density line; that is, there is a species specific maximum mean tree size that can be attained at a given number of stems per acre, without allowing for further mortality or self-thinning. On a theoretical basis, the slope of this line is expected to be at or close to -3/2 when plotted on a log-log scale (ln(mean biomass) plotted on ln(trees per acre)).

Reineke's (1933) stand density diagram relates directly to this law of self-thinning, except that he reverses the axes and applies a linear dimension (mean diameter) to describe mean tree size. Therefore, when expressed as

$$\ln D_q = b_0 + b_1 \ln TPH$$

the slope that he demonstrated across numerous species was

$$b_1 = 1/-1.605$$
$$= -0.62305$$

When the 65 individual plots of *Acacia nilotica* were plotted on this scale, surprisingly close conformity to a maximum size-density line of similar slope was exhibited (Appendix A.2). It was therefore assumed that *Acacia* followed a self-thinning line with a slope of approximately -0.62305. The maximum line was identified by finding the largest intecept, b_0, associated with the 65 lines having a slope of -0.62305 and passing through the each of the $\ln(D_q)$-ln(SPH) coordinates corresponding to the 65 plots. The resulting maximum size-density line passed through plot 14-1, and can be written as

[4] $$\max[\ln(D_q)] = 7.64411 - 0.62305 \ln(SPH)$$

where $\max[\ln(D_q)]$ = maximum $\ln(D_q)$ for a given SPH

This maximum size-density line, or self-thinning line, is the line plotted in the size-density diagram in Appendix A.2.

3.c.ii. Top height isopleths

Movement of different stands across the size density diagram is theoretically independent of site, although the *rate* of movement is assumed to be dictated by rate of growth, and

hence, by site quality. This dynamic component was added to the hury density diagram by expressing $\ln(D_q)$ as a function of both ln(SPH) and ln(top height). The equation that was fit to the 65 plots was

$$[11] \quad \ln(D_q) = \underset{(.4314)}{2.2302} - \underset{(.03385)}{0.32707} \ln(SPH) + \underset{(.08113)}{1.09530} \ln(TH)$$

$$\text{with} \quad s_{y.x} = 0.1656, \quad R^2 = .929$$

Isopleths of constant top height are plotted on the diagram in Appendix A.3. Thinking of top height as a surrogate for time within a given site index, the trajectory of an individual hury can be defined by its asymptotic approach to the maximum size-density line, at a rate defined by top height growth.

3.c.iii. Mortality estimation

The maximum size-density line represents a limit beyond which the hury is not permitted to develop; however, given this constraint there are a variety of routes which a hury can take to approach the self-thinning line (Appendix A.4). In general, these trajectories can be modeled with an equation developed by Smith and Hann (1984),

$$[12] \quad \ln(D_q) = \max[\ln(D_q)] - [b_0 b_2 - b_1 b_3 X_0] \exp[b_4 (X_0 - X)^{b_5}]$$

where $\max[\ln(D_q)]$ = maximum of $\ln(D_q)$ defined by the maximum size-density line
b_2 and b_3 = modifiers on the intercept and slope of maximum size-density line to define onset of self-thinning
X_0 = initial ln(SPH)
X = future ln(SPH)

The parameter estimates b_4 and b_5 determine the scale and shape of the asymptotic approach to the self-thinning line. A range in values of these parameters was explored and compared with current huries and measured mortality to estimate self-thinning behavior of the huries. Data are currently lacking to construct a data directed mortality model for the huries. However, under present management, variation in these trajectories will probably have a relatively minor impact for two reasons: 1) huries generally are sown and germinate at very high densities, so that 2) most huries are managed at a near maximum density regimes and hence their *movement along the self-thinning line*, rather than their *approach to the line*, dominates most of the history of a given hury.

Since equation [4] represents the absolute maximum size-density line observed, it is advisable that simulated huries be constrained to a relative density of approximately 0.80, thereby

simulating closer to an average hury. The resulting self-thinning asymptote will be

[13] $\max[\ln(D_q)] = \ln(MX) + 7.64411 - 0.62305 \ln(SPH)$

where MX = relative density defining the desired maximum size-density line

The modifier in equation [6] specified as $b_0 b_2$ can alternatively be thought of as the *relative density* at which density-dependent mortality commences. The parameter b_3 specifies the percent reduction in the slope of the initial mortality line, relative to the slope of the maximum size-density line. That is, if the line defining commencement of mortality is parallel to the maximum size-density line, b_3 will be equal to zero.

The final mortality model can be written as

[14] $\ln(D_q) = \max[\ln(D_q)] - [\ln(MX) - \ln(MOD) - (SMX)\ b_1 X_0] \exp[b_4 (X_0 - X)^{b_3}]$

where $\max[\ln(D_q)]$ = maximum of $\ln(D_q)$ defined by equation [7]
MOD = relative density at which mortality commences
SMX = percent reduction in slope of mortality line
X_0 = initial ln(SPH)
X = future ln(SPH)

The following values were chosen as the default values of the mortality parameters, although the user has the freedom to change these parameter estimates as better data or experience dictates:

MOD = 0.30
SMX = 0.0
b_4 = -4.5
b_3 = 1.00
MX = 0.80

3.d. Yield function

Hury yield functions were developed in several stages. First, equations [3] through [6] were applied to the plot data to estimate per hectare yields of each biomass component. Then, a yield function simply for total above-ground biomass was derived by searching over numerous log-log and weighted and unweighted linear and nonlinear model forms. The nonlinear models tested did not improve the fits over linear models, and no need for weighting was apparent. Among the many models tested, those presented in Table 7 performed most favorably.

Logarithmic models did not exhibit as low an index of fit as the linear models, and forcing additivity of log-log equations did not make mathematical sense. Among the best linear models, the four variable model with BA x SPH x TH interaction and the three variable model with SPH^2 were judged overly complex; hence the following linear model was selected to fit the full complement of biomass components:

[15] $Y = b_0 + b_1 SPH + b_2 BA\ TH + b_3 SPH\ TH$

where Y = total above-ground biomass, metric tons per ha
SPH = stems per hectare
BA = basal area per hectare, m^2
TH = top height, m
b_0, b_1, b_2 = coefficients estimated from the data

3.e. *Estimation of biomass components per unit area*

Total biomass was constrained to equal the sum of the component biomass predictions in a manner completely analogous to the individual tree biomass equations. Thus, define variables

x_{i1} = 1 if the observation is on component *i*
0 otherwise

x_{i2} = SPH if the observation is on component *i*
0 otherwise

x_{i3} = BA TH if the observation is on component *i*
0 otherwise

x_{i4} = SPH TH if the observation is on component *i*
0 otherwise

where *i* = 1, 2, 3, or 4, corresponding to the separate biomass fractions

The regression model then becomes

[16] $$B = \sum_{i=1}^{4} \sum_{j=1}^{4} \beta_{ij}\ x_{ij}$$

subject to the constraints that

$$\beta_{i4} = 0$$

and

$$\beta_{11} + \beta_{21} + \beta_{31} = \beta_{41}$$

$$\beta_{12} + \beta_{22} + \beta_{32} = \beta_{42}$$

$$\beta_{13} + \beta_{23} + \beta_{33} = \beta_{43}$$

$$\beta_{24} + \beta_{34} = \beta_{44}$$

The full equation was fit first; however, the SPH x TH term was not significant (p=0.302) for the fine fraction and hence was dropped from the model, as implied by the constraint $\beta_{14} = 0$. The final fit of the constrained model resulted in the following component equations:

[17] $$B(1) = \underset{(2.07932)}{-0.302528} + \underset{(.081963)}{0.512966}\ SPH + \underset{(0.0087101)}{0.307375}\ BA\ TH$$

[18] $$B(2) = \underset{(2.10209)}{12.5135} - \underset{(.168542)}{1.32515}\ SPH + \underset{(.00931387)}{0.241265}\ BA\ TH + \underset{(.0349027)}{0.308987}\ SPH\ TH$$

[19] $$B(3) = \underset{(2.10209)}{-14.8343} + \underset{(.168542)}{2.31645}\ SPH + \underset{(.00931387)}{0.495973}\ BA\ TH - \underset{(.0349027)}{0.610071}\ SPH\ TH$$

[20] $$B(4) = \underset{(2.10209)}{-2.623328} + \underset{(.168542)}{1.504266}\ SPH + \underset{(.00931387)}{1.044613}\ BA\ TH - \underset{(.0349027)}{0.301084}\ SPH\ TH$$

where
- B(1) = predicted kg of biomass per hectare in fine fraction (< 2.0 cm)
- B(2) = predicted kg of biomass per hectare in firewood fraction (between 2.0 and 6.5 cm)
- B(3) = predicted kg of biomass per hectare in pit prop fraction (between 6.5 and 17.0 cm)
- B(T) = predicted kg of total biomass per hectare of all fractions summed

Table 7. Equations for predicting total above-ground hury biomass on a per hectare basis.

Model	Weight	Furnival's index
Linear		
$Y=b_0+b_1 BA\ TH$	1	10.16
$Y=b_0+b_1 BA\ TH+b_2 TH$	1	9.58
$Y=b_0+b_1 SPH^2+b_2 BA\ TH$	1	9.64
$Y=b_0+b_1 SPH^2+b_2 BA\ TH+b_3 SPH\ TH$	1	6.74
$Y=b_0+b_1 SPH+b_2 BA\ TH+b_3 SPH\ TH$	1	7.17
$Y=b_0+b_1 BA^2+b_2 BA\ SPH+b_3 BA\ TH+b_4 BA\ SPH\ TH$	1	6.09
Logarithmic		
$\ln(Y)=b_0+b_1 BA+b_2 \ln(TH)$	1	17.98
$\ln(Y)=b_0+b_1 BA+b_2 SPH+b_3 \ln(TH)$	1	16.30
$\ln(Y)=b_0+b_1 BA+b_2 TH+b_3 (1/A)$	1	18.08
$\ln(Y)=b_0+b_1 BA+b_2 \ln(SPH)+b_3 \ln(TH)$	1	18.21
$\ln(Y)=b_0+b_1 \ln(BA)+b_2 (1/TH)+b_3 \ln(TH)+b_4 (1/A)$	1	11.59

3.f. *Estimation of pit prop grade distribution*

Total pit prop biomass ultimately is of limited value for economic analysis, since value increases exponentially with piece size. Therefore, a crude algorithm was developed for approximating the dbh distribution and estimating pit prop yields by 1-cm dbh class.

A rough approximation to the dbh distribution of a given hury was constructed as follows:

1) Minimum dbh was predicted by

[21] $$DMIN = 14.0132\ SPH^{-0.3786} TH^{1.4132} \exp(0.222/2)$$

2) Arithmetic mean dbh was predicted from D_q and other hury attributes by

[22] $$D_a = D_q - SPH^{0.0000265} TH^{1.6931} A^{2.4789} \exp(-11.693 - 0.05473\ A + 0.2304/2)$$

where D_a = arithmetic mean dbh

3) The minimum dbh was assumed to occur at 2 standard deviations away from arithmetic mean diameter.

4) The proportion of trees in each 1-cm dbh class was computed by the normal probability density function, given the mean and variance as estimated from above.

5) The total number of trees in each dbh class was computed by multiplying these proportions by total SPH.

The dimensions and weights of pit props within each grade were tabulated to estimate the combination of grades derivable from a tree with given pit prop biomass. Average fresh density of the 33 measured pit props was 68.3 lbs/ft^3 (s.d. = 6.74); hence, this figure was applied to compute average weights of the pit props shown in Table 8. Then, by considering dbh, individual pit prop weight, predicted total pit prop weight per tree, and actual pit prop recoveries from the 31 sample trees, a rule was constructed by which the number of pit props of each grade was determined for dbh classes 7-17 cm (Table 9). Finally, total pit prop distribution was obtained by multiplying the number of pit props of each grade by the number of trees in that diameter class.

Table 8. Pit prop dimensions and weights.

Grade	Girth (in)	Length (ft)	Weight (lbs)
1 - special	13	12	76.54
	14	12	88.77
	15	12	101.91
	16	12	115.95
	17	12	130.90
	18	12	146.75
	19	12	163.51
	20	12	181.17
	21	12	199.74
2 - special	13	10	63.79
	14	10	73.98
	15	10	84.92
	16	10	96.62
	17	10	109.08
	18	10	122.29
3 - special	13	9	57.41
	14	9	66.58
	15	9	76.43
	16	9	86.96
	17	9	98.17
	18	9	110.06
4 - special	13	7	44.65
	14	7	51.78
	15	7	59.45
	16	7	67.64
	17	7	76.36
	18	7	85.50
5 - ordinary	9	6	18.34
	10	6	22.65
	11	6	27.40
	12	6	32.61
	13	6	38.27
6 - ordinary	9	6	18.34
	8	6	14.49

Table 9. Pit prop recovery rules by dbh class.

Dbh class (cm)	Average predicted pit prop biomass (lbs)	Number of pit props by grade					
		1	2	3	4	5	6
7	26.39						1
8	41.07					1	
9	59.41					1	1
10	81.70					2	1
11	108.14				1	1	1
12	138.98			1	1		1
13	174.41		1	1		1	
14	214.64		1	1	1		
15	259.90	1			1	1	1
16	310.34	1			2	1	
17	366.21	1		1			2

4. *Simulation*

Instructions for running the Hury Yield Model are presented explicitly in Appendix B, and the FORTRAN code in Appendix C. The user is given the option of running the hury simulation in either metric or English units. In addition, yields of either a new or existing hury can be simulated. Once the Hury Yield Model is executed, it will request the data necessary to initiate the simulation. The stated hury specifications, the mortality model specifications, and the simulation results are automatically written to an output file specified by the user. At the end of the simulation this output file can then be printed to obtain a hard copy of the simulation results.

4.a. *Top height increment*

All simulations are driven by top height increment. However, this top height increment can be specified to remain independent of time, or it can be controlled by age through the site curves. This allows introduction of a different time scale when and if better site curves or productivity indices become available.

4.a.i. *Top height increment independent of time*

If the user specifies that the simulation be driven strictly by top height, hury attributes are updated in increments of one meter (3.3 ft) of top height growth, up through 15 meters (49 ft) total top height. The new top heights are input to equations [5] and [8], then this set of equations is solved numerically for the new SPH and D_q.

4.a.ii. *Top height increment driven by site curves*

If the user specifies that the simulation be driven by age, a new top height is predicted for each 12 months of simulation from the site index curves. The new top heights are again entered into equations [5] and [8], then the system of equations is solved numerically for the updated SPH and D_q.

4.b. *Prediction of mortality*

Mortality is estimated by assuming that all stands follow trajectories described by equation [12]. Thus, once the initial number of stems per hectare and the mortality model specifications are set, the path of the hury through the hury density diagram is determined. All that remains is the speed at which it follows this path, as dictated by either site index or time independent height growth increments. The initial number of stems per hectare for existing stands is computed by again assuming trajectories described by equation [12] and solving

equations [11] and [12] simultaneously, given current SPH and current top height.

4.c. *Prediction of quadratic mean diameter*

As with mortality, projection of quadratic mean diameter is implicit in the hury trajectories described by equation [12]. Once the number of initial stems per hectare is set for a given mortality specification, the change in stems per hectare and quadratic mean diameter for a given increment of top height is completely defined.

4.d. *Prediction of biomass yields*

During hury simulation, each of top height, stems per hectare, and quadratic mean diameter are recorded by growth period. At the end of the simulation, the predictor variables required for application of equations [17] through [20] are retrieved, allowing estimation of the component biomass yields per hectare. The forage fraction is obtained by application of equation [9], given the prediction for the total biomass of the fine fraction (< 2.0 cm). Stand attributes (age, D_q, SPH and TH) allow estimation of a diameter distribution with equations [21] and [22]. The pit prop recovery rules (Table 9) are then applied by diameter class to predict the pit prop grade distribution. Finally, if the user had requested English units, the yields and mean stand attributes are converted from metric, and either a metric or English simulation report is written to the output file specified by the user. Summary data for economic analyses are also written onto the file 'RUPEES.DAT'.

5. *Summary of yields*

Three types of hury yields can be presented to offer insights into the productivity of this forestry practice. Actual plot yields indicate actual stand biomass of the 65 measured plots. In addition, model predictions under a range of initial densities on a range of site qualities provide estimates of relative productivity under varying management scenarios. Finally, estimates of yield from the typical second year thinning/loppings indicate approximate yield from a common intermediate operation.

5.a. *Actual plot estimates*

Estimated biomass yields of the 65 measured plots are presented in Table 10, along with the mean plot attributes. The maximum total standing biomass was estimated at 619 metric tons per hectare (276 tons per acre), which occurred in a 7 ½ year old hury, but only in a small section of the hury. One 4 ½ year old hury was estimated at 343 metric tons per hectare (153 tons per acre). In general, total biomass is greater for huries of a given age with greater basal area, although differences in top height cause departures from this rule.

Table 10. Estimated biomass yields by sample plot.

Age (mos)	Basal area (m^2/ha)	Stems per ha	Site index	height (m)	Biomass in kg/ha by cm-diam class <2.0	2.0-6.5	>6.5	Total
5	.33	24500	24.6	2.2	12.48	.00	.00	12.48
17	2.42	50000	5.9	2.7	28.97	.25	.00	29.22
17	6.38	44000	8.1	3.7	30.97	8.56	.00	39.53
17	11.37	33000	9.6	4.4	34.08	23.72	.00	57.80
18	5.70	11500	8.8	4.3	14.29	12.89	.00	27.17
18	17.44	56500	12.1	5.8	60.11	47.26	.00	107.36
29	6.64	7500	8.5	6.2	16.74	15.86	9.22	41.82
29	6.82	3000	11.9	8.6	19.23	26.50	10.55	56.28
29	6.95	1000	8.6	6.3	14.67	12.07	20.69	47.44
29	8.66	1700	12.2	8.8	24.67	24.83	28.83	78.32
29	10.26	20500	8.3	6.0	29.00	27.86	.00	56.86
29	12.92	1800	15.3	11.1	42.78	38.70	56.95	138.43
29	13.71	3500	10.7	7.8	35.90	38.29	37.34	111.53
29	14.47	6000	11.7	8.5	40.92	63.81	15.16	119.89
29	15.15	7250	10.8	7.9	40.49	58.68	18.34	117.51
29	16.62	8250	11.3	8.2	44.25	56.80	26.91	127.96
29	24.37	5000	14.2	10.3	79.00	80.32	91.69	251.01
29	35.25	7750	12.1	8.8	100.93	99.08	120.03	320.03
30	13.06	6500	10.1	7.5	34.29	60.49	2.99	97.77
30	13.73	5750	12.2	9.1	40.00	54.74	23.32	118.05
41	11.14	3100	8.3	7.3	27.16	30.82	25.83	83.80
41	11.82	6750	7.4	6.5	27.04	44.02	5.10	76.16
41	12.25	12750	7.1	6.3	30.88	43.88	.00	74.76
41	14.44	18500	9.5	8.4	43.67	56.91	4.63	105.21
41	15.04	4250	11.9	10.5	49.68	60.88	42.46	153.02
41	16.71	5500	11.4	10.1	53.20	64.73	42.76	160.74
41	16.72	3000	9.3	8.3	44.82	40.20	58.94	143.95
41	18.23	5750	10.8	9.5	54.65	67.53	44.89	167.07
41	19.49	6750	10.0	8.8	57.25	59.25	59.39	175.89
41	19.57	7500	10.2	9.1	57.69	68.42	47.09	173.20
41	19.76	12000	10.9	9.6	59.48	90.42	15.41	165.31
41	20.67	3300	11.9	10.5	67.76	67.11	81.91	216.79
41	22.20	1750	10.1	9.0	65.65	54.65	96.80	217.10
41	23.56	14750	9.7	8.6	65.33	85.43	33.60	184.36
41	27.72	5500	11.9	10.5	92.75	94.97	106.83	294.55

Table 10. Continued

					Biomass in kg/ha			
Age	BA	SPH	SI	TH	<2.0	2.0-6.5	>6.5	Total
47	23.76	3500	12.8	11.9	88.43	85.97	109.37	283.77
47	28.32	3500	11.0	10.3	88.92	80.76	119.46	289.14
53	13.60	7750	7.7	7.5	34.49	55.28	7.23	97.00
53	17.03	3750	10.3	10.0	53.01	60.47	53.35	166.84
53	18.13	6250	9.8	9.5	54.76	68.74	42.41	165.91
53	20.18	5500	10.0	9.7	61.52	71.56	56.18	189.06
53	20.57	3250	12.5	12.2	79.70	80.67	94.95	255.32
53	20.59	6750	10.6	10.3	66.18	78.35	56.20	201.23
53	21.04	7500	10.6	10.3	67.75	88.32	46.96	203.04
53	21.80	10750	10.0	9.7	66.65	84.52	40.61	191.78
53	24.53	6000	9.9	9.6	71.46	79.40	71.95	222.80
53	25.08	6000	10.4	10.1	81.71	87.59	86.49	255.79
53	25.17	5500	10.2	9.9	85.77	91.11	93.35	270.22
53	25.90	7000	11.1	10.8	88.73	96.77	88.69	274.19
53	29.96	4750	11.8	11.4	107.33	107.54	128.22	343.08
65	13.09	1600	12.0	12.2	51.58	49.68	65.26	166.52
65	13.21	2250	11.9	12.0	51.82	52.52	59.61	163.95
65	17.93	4000	11.8	12.0	66.47	72.49	69.11	208.08
65	19.53	6500	10.4	10.6	63.05	81.71	44.88	189.63
65	20.35	3250	10.6	10.8	69.11	65.80	86.70	221.62
67	20.09	2900	11.2	11.4	69.69	65.94	89.38	225.00
67	20.64	8500	8.6	8.8	58.58	71.56	44.46	174.61
74	14.81	2300	9.0	9.3	49.40	47.23	61.82	158.45
74	18.08	4000	11.5	11.9	66.43	78.22	62.21	206.86
74	26.51	8250	9.5	9.8	83.82	106.49	64.67	254.98
80	13.18	9250	7.6	7.9	34.61	49.36	9.69	93.66
80	15.37	1900	10.5	10.9	54.54	50.35	71.65	176.55
80	19.02	3500	10.3	10.8	65.36	70.65	70.80	206.81
89	32.68	2500	12.6	13.2	136.52	117.65	195.74	449.91
89	45.97	3500	12.4	13.0	187.51	158.27	273.30	619.08

5.b. *Predicted yields by age, initial density, and site quality*

Simulation runs allow the user to explore the ramifications of a range in hury and site conditions. Two sample output files are presented in Appendix D, the first being the result of a simulation in metric units, and the second a simulation in English units.

By performing a series of model predictions, yields for ages one through eight can be seen to vary both by site quality and initial density. General results are not surprising: larger trees and hence larger pit props are yielded under lower initial densities, and total yields are greater on higher site qualities, at a given age. Other trends in diameter and pit prop distribution across different initial densities can also be observed, as can the response of the various biomass fractions.

5.c. *Yields from thinning/pruning*

The two plots that were measured for pruned branch diameters (plots 4-2 and 30-1) had no cut stumps present. Applying equation [7] to the tally of pruned branches with subsequent expansion by the reciprocal of plot size gave estimates of the total forage biomass produced by the pruning. The two estimates of forage biomass were:

Plot 4-2 :	2.6725 metric tons per ha
Plot 30-1 :	0.2621 metric tons per ha

Plots 4-2 and 30-1 contained 12,750 and 3,500 stems per hectare, respectively. The pruning on plot 4-2 resulted in approximately 189,500 pruned branches per hectare with an average diameter of 0.87 cm. The pruning on plot 30-1 summed to approximately 144,250 pruned branches per hectare with an average diameter of 0.52.

6. Economic Synthesis

A hury typically is established by broadcast or line sowing of acacia seeds together with agricultural crops. In Sind, only one agricultural crop is generally interplanted during the first year, and this crop tends to be cotton. Because of the agricultural crop in the first year, scarce irrigation water is allocated by the farmer to the hury as it would be to any other parcel growing agricultural crops. From the second year on, water is allocated to the hury on a residual basis only; i.e., after all other parcels with agricultural crops have received the necessary or available amount. Because of this practice, irrigation in the yield model was not treated as a separate decision variable; rather it is accounted for implicitly in the site index.

After the hury is harvested, the parcel of land reverts back to agriculture. Because acacia nilotica is a nitrogen fixer, no fertilization is needed for the first two to four agricultural crop rotations following the hury. After a greatly variable number of crop rotations (this number apparently depending on the rate of siltation and hardpan formation and the need and market for hury products), the parcel can be allocated back to hury management.

The economic synthesis is restricted to one hury rotation. To present the overall economic synthesis for the rotation, an internal rate of return is calculated and presented for each management alternative adopted in the yield model. Since cash flow is an important (sometimes overriding) consideration for farmers, the revenue and cost stream per year is presented as well.

a. Data Collection

Data on costs and revenues were collected through interviews with the farmers. These data were checked and amplified by the principal authors in discussions with knowledgeable field experts from the Sind forestry service and other agencies. Where no data were available, best estimates from elsewhere were used (and indicated for the specific cost and revenue category). In the simulation of the module, the user can substitute different numbers for the costs and revenues.

b. Costs

i. Site preparation costs were put at 815 Rp/ha. This includes all costs to prepare the site for sowing the acacia seeds (generally consisting of ripping up rows) and for the cotton crop.

ii. Cost of acacia seeds for sowing was put at 25 Rp/ha.

iii. Cost of cotton plants was put at 100 Rp/ha.

iv. Labor costs were incurred for sowing the acacia and planting the cotton during the first year, as well as for minimal tending, irrigating the land, and harvesting the cotton crop. In subsequent years, labor is needed to tend the huries and to collect foliage, small branches, and pods for fodder, cut firewood and pitprops, and irrigate the parcel (if applicable).

	YEAR							
Labor Costs +irrigation charges (in Rp/ha)	1	2	3	4	5	6	7	8
	644	1,040	742	742	618	600	600	600

v. Cost of pesticides was put at 500 Rp/ha.

vi. Cost of fertilizer was put at 406 Rp/acre, or about 1,000 Rp/ha.

vii. A land rent of 1,000 Rp/ha was adopted to cover the cost of using the land.

viii. Irrigation water is reportedly free; however, a nominal fee of 20 Rp per application is used, with 4 applications assumed for the first year. Since during subsequent years (2, 3, etc.), water is made available only to the extent that it is surplus, only 125 Rp/ha were assumed paid for irrigation.

c. Revenues

i. The cotton crop was estimated to bring up to 10,000 Rp/ha during the first year, assuming 15-20 mds/acre.

ii. Loppings and foliage produced and sold for fodder at Rp 500/Kg. The foliage and the forage proportions in fine fraction are produced by the yield model (100 for third year, 184 for fourth year, and 216 for fifth year).

iii. The fine fraction proportion not used for forage is assumed to be used for windrow fencing. Assuming that windrowing costs equal revenues received, no net revenue is used. This probably results in a slight underestimate of net revenue since a fraction of this normally is used as fuelwood.

iv. The fuelwood yield per year in kg/ha as produced by the yield model is converted into revenues assuming the price for fuelwood that is represented in the program.

v. Amounts and grades of pitprops produced at different ages from the yield model are converted to revenues using the following prices:

Grade	Price (Rp)/Piece
1	30
2	20
3	27
4	16
5	9
6	5

vi. No specific data were available on the amount of nitrogen produced by acacia and available for subsequent crop rotations. Two indirect measures of this revenue were available:

-- Studies of alder (Alnus) and ipal-ipal (Leucena) show that amounts equal to 100 pounds of urea/acre or 125 kg/ha are not unreasonable. This would translate into ...Rp/ha.

-- Since no fertilizer is needed for the first 2-4 crops after a hury rotation and since a fertilization tends to cost 300 Rp/ha, the benefit of acacia nitrogen fixation would run to 1,500-3,000 Rp. This assumes two bags of DAP and one bag of urea for cotton, and one bag of DAP and one bag of urea for wheat.

vii. Huries produce other benefits. Acacia flowers twice per year in Sind, producing biannual honey crops. In addition, the flowers are gathered and used for medicinal purposes. While the tree flowers biannually, it produces pods only annually; the pods, eaten by animals, are not reflected in the foliage or fine fraction forage

produced by the yield model, and thus are an additional benefit. At harvest, the bark of acacia often is used for tanning. Finally, the major roots and stumps at harvest are used for fuel; since they are difficult to gather (but at the same time have to be removed to make a place for the agricultural crops), it is assumed that costs of removal equal revenues received. Together, these benefits are estimated to amount to 2,600 Rp/ha (or 2,324 + 216).

d. Economic Calculations

Each of the cost and revenue amounts can be changed. The computer, using the yield model outputs and the costs and revenues specified in sections b and c, produces an annual net revenue statement. In addition, an internal rate of return is calculated for a hury rotation for each management alternative.

7. *Recommendations for further work*

It cannot be overemphasized that this current version of the Hury Yield Model should be considered a temporary, first approximation. Numerous components seriously need further refinement. The framework constructed in the current project, however, should serve as an effective model for both interim projection of hury yields and identification of data needs for future improvements.

7.a. *Growth data*

The data from which the Hury Yield Model was constructed were *yield* data, not *growth* data. To accurately project hury growth under varying silvicultural regimes, collection of the latter type of data is essential. Note that this will require establishment of permanent or semi-permanent plots. By securing growth data over a range of stand and site conditions, direct prediction of growth will be facilitated, and insights into hury growth will progress beyond simple estimates of yield.

7.b. *Mortality data*

The lack of mortality data for Version 1.0 should also be stressed; the mortality model at present is based only on the general biological principle of a maximum size-density relationship and the subjective design of an asymptotic approach to this maximum size-density line. Although this modeling approach has been taken quite successfully in North American forest growth models, and hence is expected to perform well for *Acacia* plantations, parameter estimates need to be more firmly based on data from permanent or semi-permanent plots. Considerable flexibility exists in the current version for adjusting mortality rates commensurate with local observations, but it should also be kept in mind that predicted yields can be rather sensitive to changes in mortality specifications.

7.c. *Biomass equations*

The individual tree biomass equations were based on a fairly limited sample size; however, quite satisfactory fits were obtained suggesting that, although additional data would result in slight changes in parameter estimates, predictive power would not be drastically improved. In contrast, finer resolution in the predctions would confer greater insights especially into the economic impications of various management options. The forage fraction of the finest biomass component could also be improved in regard to both parameter estimation and definition of exactly what constitutes this fraction.

7.c.i. Conversion to pit prop grades

For economic analysis the most glaring deficiency of the current version is the crude level of product size class information. One immediate approach to improving the current technique for constructing a diameter distribution would be to apply the method of moments to recover the parameters of an assumed diameter distribution (Hyink and Moser 1983). Limited success was obtained in a first attempt to impose either a Weibull or normal diameter distribution on simulated huries in this manner. However, a parameter recovery approach would ensure compatibility of the diameter distribution with model predictions of basal area per unit area, unlike the current approach. It should also be pointed out that the lack of taper equations (and the difficulty of developing them) limits the utility of diameter distributions, unless rules such as those presented in Table 9 prove sufficient. It also would be worthwhile to consider continuing the hury rotation up to 15 years so that sawtimber and poles are produced, thereby allowing assessment of the economic advantage/disadvantage of extended rotation lengths.

7.c.ii. Estimation of the forage fraction

More data are needed to produce better estimates of the the fraction of fine (< 2.0 cm) biomass contributed by forage material, including both foliage and succulent twigs. On one level, the sample size simply needs to be increased. In addition, however, relying on random samples of 2.0 cm branches is not ideal. Some of the branch material < 2.0 cm derives from branches which are considerably smaller than 2.0 and which emanate directly from woody material much greater than 2.0 cm. If the forage fraction of these smaller branches deviates substantially from the fraction of 2.0 cm branches, a potential bias could accrue by sampling only 2.0 cm branches. An improved design would provide for random sampling of all branches which are < 2.0 cm and which emanate from a branch or bole > 2.0 cm.

7.c.iii. Definition of forage fraction

Considerable uncertainty is apparent in identifying exactly what material is consumed as forage by goats (or any other livestock). Although it is rather straightforward to separate foliage from twigs and woody material, the fact that local villagers present widely differing views of the diameter of twig material consumed by goats introduces further variance into estimates of forage biomass. An accurate definition of forage material is required for improved estimates of this biomass component.

7.d. Response of huries to cultural practices

The current data base is rather inadequate for projecting response of huries to heavier levels of thinning than currently

practiced. Therefore to explore fully the economic implications of intensive and heavy thinning schedules, experimental plots will have to be established either on land administered by the Sind Forest Department or on land owned by cooperating landowners. These plots must receive a range in initial sowing densities and subsequent thinning schedules, thereby facilitating identification of growth responses to the full range of possible management regimes.

Other cultural treatments, such as the effect of broadcast vs. drill seeding, or the response to fertilization, can also be explored; the effects of many of these treatments will have to be assessed by tightly controlled experiments.

7.e. Productivity index

Productivity of huries appears to be closely related to the amount of irrigation received. Thus, application of classical site index procedures will always leave much room for improvement. At the next stage, either a new productivity index could be researched or better site index equations could be constructed.

7.e.i. Improved site index curves

The guide curve technique applied in construction of the current site index curves contains several stong assumptions about the data. Probably most important is the assumption that the same distribution of site quality classes is represented at all ages of sampled huries. Also, the shape of top height growth for all site indices is assumed constant; that is, the site index curves are all constant proportions of one another. Greater flexibility in modeling top height growth is introduced by obtaining time series data on the cumulative height growth of individual trees. This approach will prove difficult in *Acacia* since this type of data is usually collected by stem sectioning and aging by growth rings. However, repeat measurements on individual trees, if done in a quality manner, can also generate the data needed for more sophisticated techniques of constructing site index equations.

7.e.ii. Index of irrigation amount/frequency

The ideal productivity index would abandon site index altogether, and instead rely on some numerical index of irrigation frequency or irrigation amount. In essence, a cutoff of irrigation water, or an acceleration in frequency and amount, would change the apparent site index since top height growth would drastically decelerate or accelerate, respectively. Thus keying the productivity index into its major determinant rather than current cumulative top height growth offers considerable appeal. Experimentation at Miani or close control and documentation of irrigation on plots on private land could yield the required data.

7.f. Economic assumptions

The economic information on costs and revenues are subject to change. This can easily be handled. More interesting would be to embed the results of the more important simulations runs into a general linear programming framework to evaluate where the farmer should allocate his efforts and resources. A linear programming model which would maximize net (discounted) revenue of the whole farm for the different possible agricultural hury crops, subject to constraints on available irrigation water, labor (perhaps separated for women and men, tenant, and owner), capital, land parcel suitability, etc., on a monthly basis would be quite revealing and potentially of tremendous practical significance.

8. Conclusion

Comparison of hury yields to published estimates of net annual primary production indicates that the mean annual increment of huries rivals some of the most productive forest systems in the world (Art and Marks 1971). As a private forest practice yielding attractive profits for the landowner, hury management can borrow from many techniques in classical timber management. Hury silviculture is a prime example of intensive plantation management, differing from other foresty practices only in regard to the closer utilization standards and wider variety of outputs. As a result, classical silvicultural questions are directly pertinent to hury management, including definition of cultural regimes likely to produce optimal quantities and qualities of pit props and firewood. Specifically, the influence of different initial spacings and various thinning schedules requires definition, but perhaps of greater importance for pit prop value is the interaction of pruning with different stand density regimes. Again, these are all classical timber management problems, but in the context of huries, closer utilization of leaves and branches necessitates consideration of several other outputs as they are affected by silvicultural manipulation. The described Hury Yield Model and ecoNomic Synthesis attempts to construct an initial framework for gaining better insight into these issues of hury management.

9. *Literature cited*

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10. A P P E N D I C E S

A.1. Site index curves.

A.2. Hury size-density diagram.

A.3. Top height isopleths on hury size-density diagram.

A.4. Hury size-density trajectories.

A.5. Field data forms.

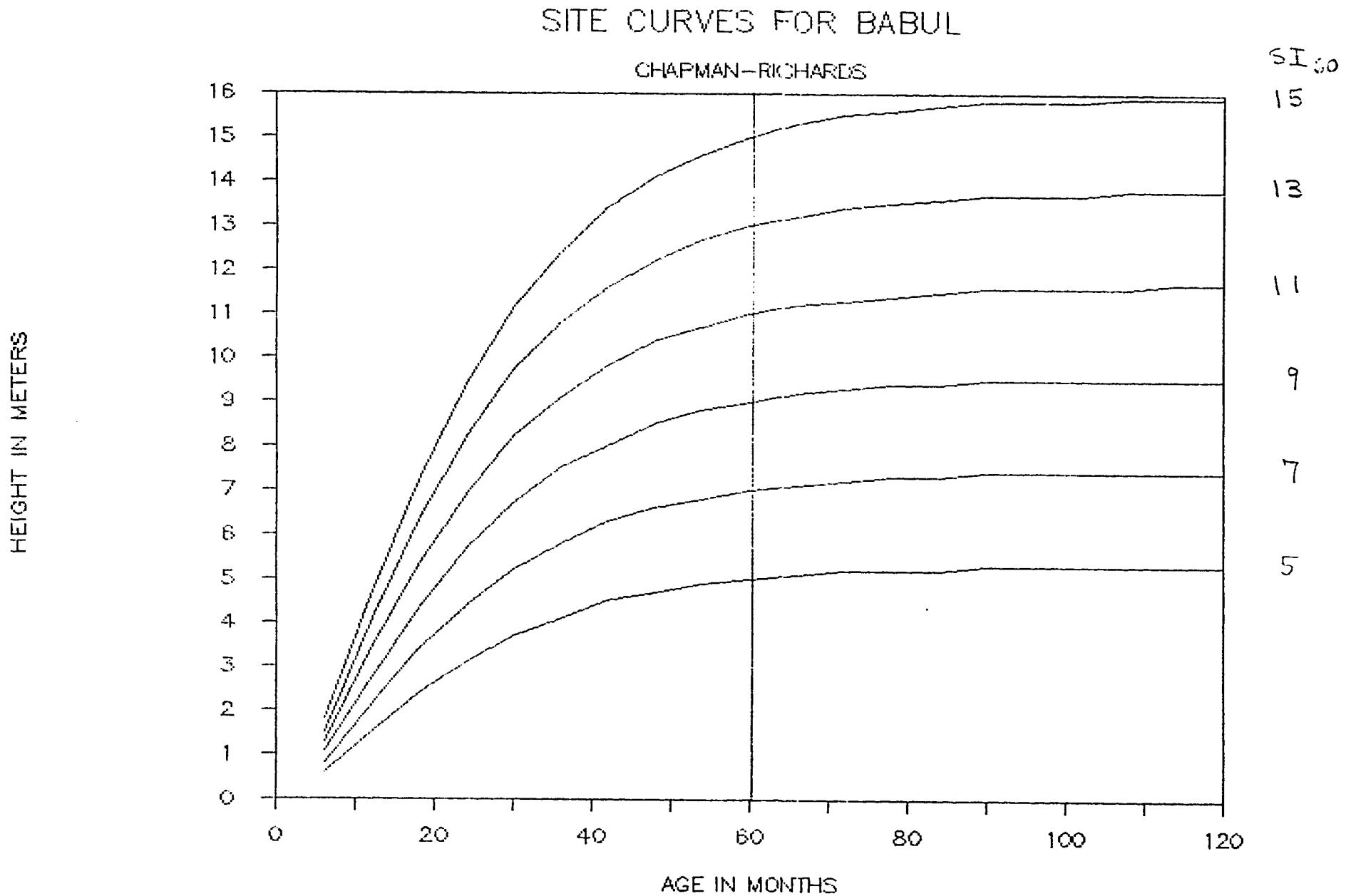
B. Direction for running the Hury Yield Model.

C. FORTRAN code for the Hury Yield Model.

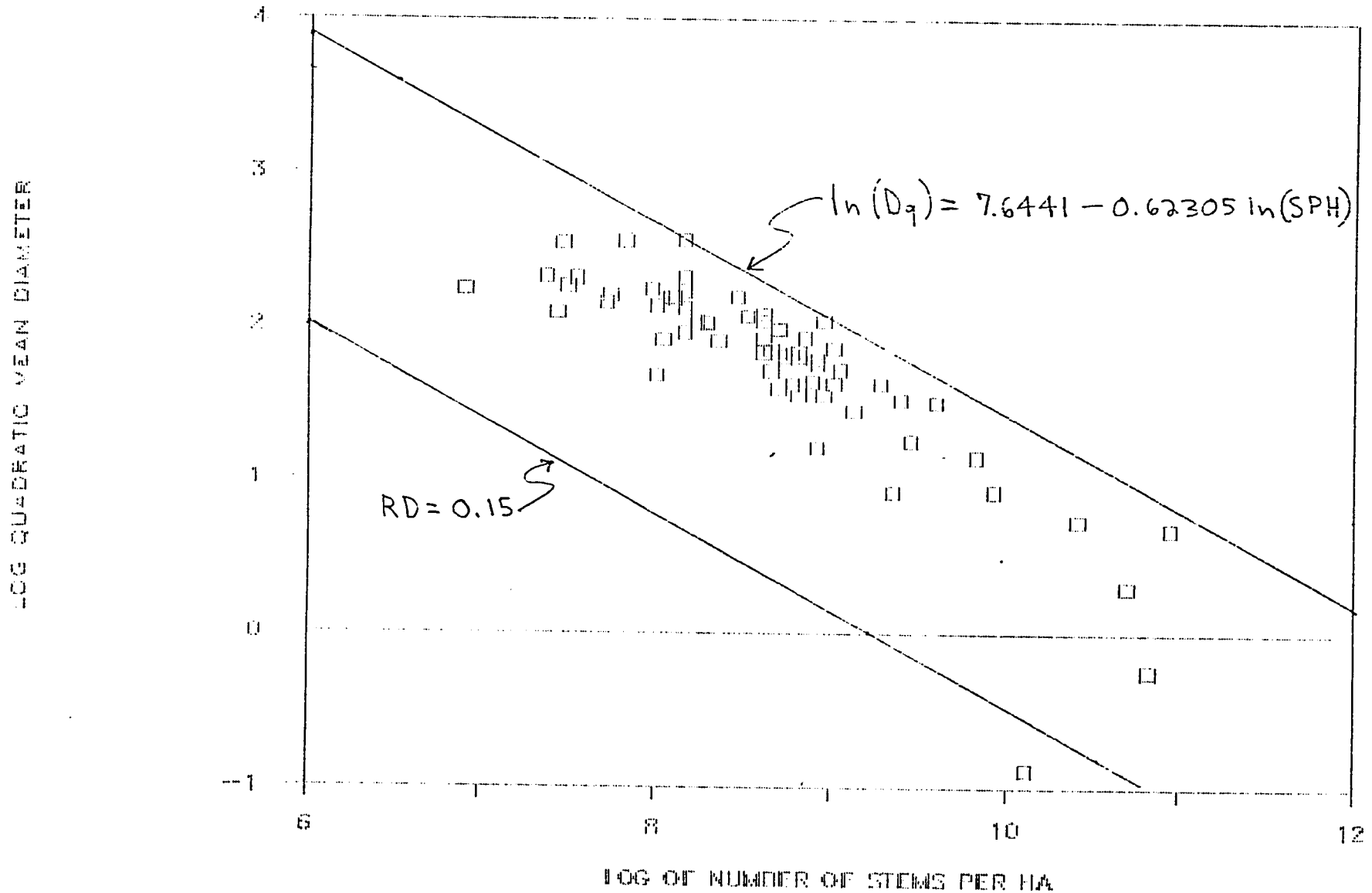
D. Sample output files from simulation runs.

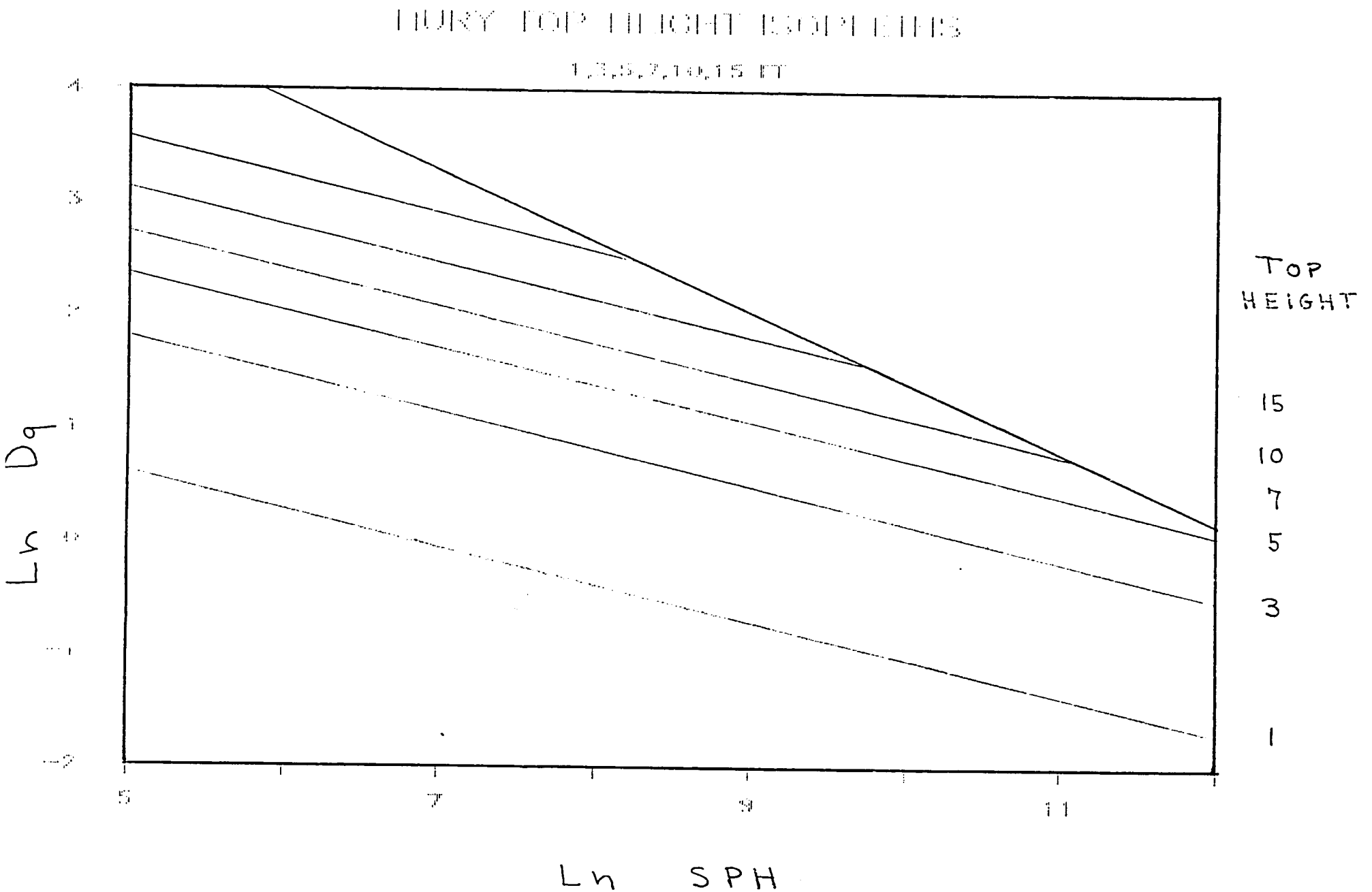
E. Economic analysis.

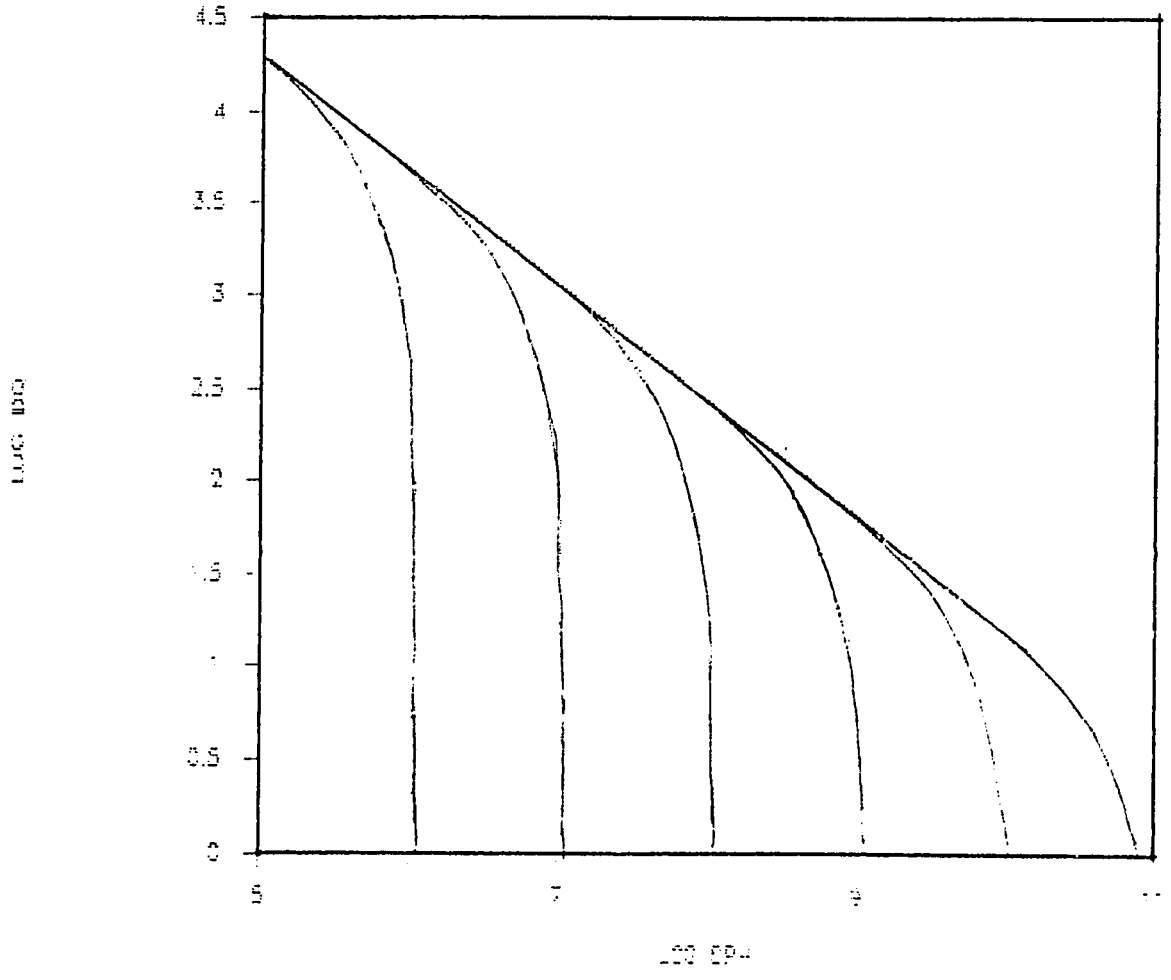
Appendix A


SITE CURVES FOR BABUL
CHAPMAN-RICHARDS
HEIGHT IN METERS
AGE IN MONTHS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
20
40
60
80
100
120
SI 50
15
13
11
9
7
5

HURY PLOTS


ln(Dq) = 7.6441 − 0.62305 ln(SPH)
RD = 0.15
LOG QUADRATIC MEAN DIAMETER
LOG OF NUMBER OF STEMS PER HA
4
3
2
1
0
−1
6
8
10
12


HURY TOP HEIGHT ISOPLETHS
1,3,5,7,10,15 FT
Ln Dq
Ln SPH
TOP HEIGHT
15
10
7
5
3
1
5
7
9
11



MOD = 0.35
SMX = 0
b_4 = -4.5
b_5 = 1.00
MX = 0.80

BEST AVAILABLE DOCUMENT

HURRI IDENTIFIERS _____ DATE _____

_____

_____ PLOT SIZE _____

_____

PLOT	SPECIES	DBH	TOTAL HEIGHT	CLEAR BOLE LENGTH				

HURRI IDENTIFIERS _____ DATE _____

_____

_____ PLOT SIZE _____

_____

HURRI IDENTIFIERS _____ DATE _____

_____

_____ PLOT SIZE _____

_____

HURRI IDENTIFIERS _____ DATE _____

1. Species (Acni=*Acacia nilotica*, Dasi=*Dalbergia sissoo*, Euc=*Eucalyptus*)
2. Tree establishment method and date (mo-yr) (RS=row seed, BS=broadcast seed, PL=planted
3. Species and date of agricultural crop planting (CO=cotton, GR=grain)
4. Irrigation
   a. Type (REG=regular, SEC=secondary to agr. crops, SEEP=seepage only)
   b. Frequency (in days)
5. Soil (1=well drained, fertile; 2= intermediate in drainage and fertility; 3=saline/waterlogged)
6. Topography
7. Farm attributes
   a. Size (total, agric., trees, fallow)
   b. Available labor, type and number (F=farmer, FAM=farmer + family, TEN=tenants)
   c. Cattle grazing (type, number, duration)
   d. Water constraints (when, how long)

8. Management activities	DATE	COST		REVENUE	
		RATE	TOTAL	RATE	TOTAL
a. Land rent					
b. Site prep					
c. Water for irrigation					
d. Labor for irrigation					
e. Agricultural crops, seed					
" , tending					
" , harvest					
f. Tree establishment					
g. Lopping					
h. Thinning					
i. Final tree harvest (includes roots & stumps?)					

HURRI IDENTIFIERS _____ DATE _____

9. Other activities

	DATE	COST		REVENUE	
		RATE	TOTAL	RATE	TOTAL
a.					
b.					
c.					
d.					
e.					
f.					
g.					
h.					
i.					
j.					
k.					
l.					
m.					
n.					
o.					
p.					
q.					
r.					
s.					
t.					
u.					
v.					
w.					
x.					

HURRI IDENTIFIERS _____ DATE _____

Appendix B

To Run the Hury Yield Model

1. Turn on power for the IBM PC/XT/AT microcomputer.
2. Press 'CAPS LOCK' key.
3. Place HYMNS diskette in floppy diskette drive A.
4. If not currently on Drive A, type

   A:

5. Type HYM, then press <Return>.
6. Answer all the questions that the program prompts for, following each answer with a <Return>.
7. If at any time the user would like to start over, press Ctl-C, and start at (4) above.
8. After simulation is completed, print the output file by typing

   PRINT outputfilename

To reset the yield model mortality specifications

1. Type

   SPEC

   and press <Return>, then answer the prompts, ending each answer with <Return>.

2. If you do not want to change the default values of the mortality parameters, press <Return> five times after executing SPEC.

Appendix C

```
SDEBUG
      PROGRAM GRO
*----------THIS PROGRAM SERVES AS THE CORE OF THE HURY YIELD MODEL
*            (HYM).  THE PROGRAM REQUESTS THE INITIAL INFORMATION
*---------  REQUIRED TO SIMULATE A HURY.
      INTEGER SPH,AGE,ISPH,I
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX.H1,MOD,MORT,
     +     LDQ0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX,B4,B5
      CHARACTER OUT*10,DRIVE*3,UNITS*3,RES*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH.SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
      COMMON /OU/OUT
      OPEN(3,FILE='SPEC.DAT')
C-------INPUT MORTALITY MODEL SPECIFICATIONS
      READ(3,3001) MOD,SMX,B4,B5,MX
 3001 FORMAT(F4.2,F5.2,F6.1,F6.2,F5.2)
C-------OPEN OUTPUT FILE FOR ECONOMIC ANALYSIS
      OPEN(4,FILE='RUPEES.DAT',STATUS='NEW')
C-------SPECIFY OUT PUT FILE
    7 WRITE(*,9999)
 9999 FORMAT(///1X,'PLEASE STATE THE NAME OF YOUR OUTPUT FILE:')
      READ(*,9998) OUT
 9998 FORMAT(A10)
      OPEN(2,FILE=OUT,STATUS='NEW')
C-------CHOOSE BETWEEN METRIC OR ENGLISH UNITS
      WRITE(*,9994)
 9994 FORMAT(//1X,'WOULD YOU PREFER ENGLISH OR METRIC UNITS?'/
     +         1X,'TYPE [E] FOR ENGLISH OR [M] FOR METRIC:')
      READ(*,9993) UNITS
 9993 FORMAT(A3)
C-------COMPUTE APPROPRIATE CONVERSION FACTORS
      IF(UNITS.EQ.'E') THEN
        CON1=2.54
        CON2=2.47
        CON3=0.3048
      ELSE
        CON1=1
        CON2=1
        CON3=1
      ENDIF
C-------SPECIFY SIMULATION OF A NEW HURY FROM BARE GROUND OR
C         AND EXISTING HURY
      WRITE(*,9985)
 9985 FORMAT(//1X,'WOULD YOU LIKE TO GROW A NEW OR AN EXISTING HURY?'/
     +        1X,'[N] FOR NEW HURY'/
     +        1X,'[E] FOR EXISTING HURY:')
      READ(*,9993) TYPE
```

```
C--------INPUT ATTRIBUTES OF NEW OR EXISTING HURY
      IF(TYPE.EQ.'N') THEN
        CALL NEWIN
      ELSE
        CALL EXIN
      ENDIF
C--------EXPRESS
C--------DISPLAY RECORDED HURY ATTRIBUTES
      IF(UNITS.EQ.'M') THEN
        WRITE(*,7777) SPH,TH,AGE,SI
        WRITE(2,7777) SPH,TH,AGE,SI
 7777   FORMAT(//1X,'YOUR HURY STARTS WITH THE FOLLOWING ATTRIBUTES:'//
     +        3X,'STEMS PER HECTARE  = ',I6/
     +        3X,'TOP HEIGHT, METERS = ',F5.1/
     +        3X,'AGE                = ',I4/
     +        3X,'SITE INDEX, METERS = ',F5.1///)
        IF(SPH.GT.50000.OR.SPH.LT.1000) THEN
          WRITE(*,6789)
 6789     FORMAT(//1X,'DESIRED STAND DENSITY IS OUT OF DATA RANGE !')
          STOP
        ENDIF
        IF(SI.GT.14.OR.SI.LT.6) THEN
          IF(DRIVE.EQ.'A') THEN
            WRITE(*,6788)
 6788       FORMAT(//1X,'DESIRED SITE INDEX IS OUT OF DATA RANGE !')
            STOP
          ENDIF
        ENDIF
        WRITE(*,7277)
 7277   FORMAT(1X,'DO YOU WANT TO RESTART THE MODEL?'/
     +        3X,'[Y] FOR YES'/
     +        3X,'[N] FOR NO:'/)
      ELSE
        WRITE(*,6777) SPH,TH,AGE,SI
        WRITE(2,6777) SPH,TH,AGE,SI
 6777   FORMAT(//1X,'YOUR HURY STARTS WITH THE FOLLOWING ATTRIBUTES:'//
     +        3X,'STEMS PER ACRE   = ',I6/
     +        3X,'TOP HEIGHT, FEET = ',F5.1/
     +        3X,'AGE              = ',I4/
     +        3X,'SITE INDEX, FEET = ',F5.1///)
        IF(SPH.GT.20200.OR.SPH.LT.400) THEN
          WRITE(*,6789)
          STOP
        ENDIF
        IF(SI.GT.46.OR.SI.LT.20) THEN
          WRITE(*,6788)
          STOP
        ENDIF
        WRITE(*,7377)
 7377   FORMAT(1X,'DO YOU WANT TO RESTART THE MODEL?'/
     +        3X,'[Y] FOR YES'/
     +        3X,'[N] FOR NO:'/)
      ENDIF
      READ(*,9900) RES
 9900 FORMAT(A3)
      IF(RES.EQ.'Y') GO TO 7
```

```
C-------RECORD MORTALITY SPECIFICATIONS IN OUTPUT FILE
      WRITE(2,2222) MOD,SMX,B4,B5,MX
 2222 FORMAT(//1X,'MORTALITY SPECIFICATIONS ARE:'/
     +          6X,'MOD = ',F6.2/
     +          6X,'SMX = ',F6.2/
     +          6X,'B4  = ',F6.2/
     +          6X,'B5  = ',F6.2/
     +          6X,'MX  = ',F6.2)
C-------CONVERT TO METRIC
      SPH=SPH*CON2
      TH=TH*CON3
      SI=SI*CON3
C-------GROW HURY WITH SUBROUTINE GROWE IF SIMULATING EXISTING HURY
C------- AND SUBROUTINE GROWN IF NEW HURY
      IF(TYPE.EQ.'E') THEN
        CALL GROWE
      ELSE
        CALL GROWN
      ENDIF
      CALL REPORT
      STOP
      END
```

```
$DEBUG
      SUBROUTINE NEWIN
C--------THIS SUBROUTINE REQUESTS INPUT FOR SIMULATING A NEW HURY
      INTEGER AGE,SPH
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     +     LDQ0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX
      CHARACTER OUT*10,DRIVE*3,UNITS*3,ANS*5
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
      AGE=0
      TH=0
C-------REQUEST INITIAL NUMBER OF STEMS PER UNIT AREA
      IF(UNITS.EQ.'M') THEN
        WRITE(*,9995)
 9995   FORMAT(//1X,'PLEASE ENTER INITIAL NUMBER OF STEMS PER HECTARE:')
      ELSE
        WRITE(*,8995)
 8995   FORMAT(//1X,'PLEASE ENTER INITIAL NUMBER OF STEMS PER ACRE:')
      ENDIF
      READ(*,9996) SPH
 9996 FORMAT(I7)
C-------ALLOW HURY SIMULATION TO BE DRIVEN BY AGE OR TOP HEIGHT
      WRITE(*,9997)
 9997 FORMAT(//1X,'WOULD YOU LIKE TO GROW THE HURY BY AGE',
     +          ' OR TOP HEIGHT?'//
     +          1X,'[A] FOR AGE'/
     +          1X,'[H] FOR TOP HEIGHT:')
      READ(*,9993) DRIVE
 9993 FORMAT(A3)
C-------INPUT SITE INDEX
      IF(DRIVE.EQ.'A') THEN
        IF(UNITS.EQ.'M') THEN
          WRITE(*,9988)
 9988     FORMAT(//1X,'PLEASE ENTER SITE INDEX IN METERS',
     +            ' [BASE AGE 5 YRS OR 60 MONTHS]:')
        ELSE
          WRITE(*,8988)
 8988     FORMAT(//1X,'PLEASE ENTER SITE INDEX IN FEET',
     +            ' [BASE AGE 5 YRS OR 60 MONTHS]:')
        ENDIF
        CALL ANSCHK(SI)
      ELSE
        SI=0
      ENDIF
      RETURN
      END
```

```
C-------SUBROUTINE FOR READING SI IN FREE FORMAT
      SUBROUTINE ANSCHK(XNUM)
      INTEGER K
      REAL XNUM
      CHARACTER*5 ANS
   80 READ(*,'(BN,A5)')ANS
      DO 82 K=1,5
      IF((ANS(K:K) .LT. '0' .OR. ANS(K:K) .GT. '9') .AND.
     1      ANS(K:K) .NE. '.' .AND. ANS(K:K) .NE. ' ')THEN
            WRITE(*,85)
            GO TO 80
      ENDIF
   82 CONTINUE
      IF(ANS .EQ. ' ')THEN
             WRITE(*,85)
   85        FORMAT(14X,'*** ERROR - REENTER ---> '\)
             GO TO 80
      ENDIF
      DO 90 K=1,5
      IF(ANS(K:K) .EQ. '.')THEN
            READ(ANS,'(F5.1)')XNUM
            GO TO 100
      ENDIF
   90 CONTINUE
      READ(ANS,'(BN,I5)')K
      XNUM=REAL(K)
  100 RETURN
      END
```

```
$DEBUG
      SUBROUTINE EXIN
C-------THIS SUBROUTINE REQUESTS INPUT FOR SIMULATION OF EXISTING HURY
      INTEGER AGE,SPH
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     +     LDQ0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX
      CHARACTER OUT*10,DRIVE*3,UNITS*3,ANS*5
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
C-------REQUEST INPUT OF NUMBER OF STEMS PER UNIT AREA
      IF(UNITS.EQ.'M') THEN
        WRITE(*,9995)
 9995   FORMAT(//1X,'PLEASE ENTER CURRENT NUMBER OF STEMS PER HECTARE:')
      ELSE
        WRITE(*,8995)
 8995   FORMAT(//1X,'PLEASE ENTER CURRENT NUMBER OF STEMS PER ACRE:')
      ENDIF
      READ(*,9996) SPH
 9996 FORMAT(I7)
C-------ENTER CURRENT TOP HEIGHT OF EXISTING HURY
      IF(UNITS.EQ.'M') THEN
        WRITE(*,9992)
 9992   FORMAT(//1X,'PLEASE ENTER CURRENT TOP HEIGHT IN METERS:')
      ELSE
        WRITE(*,8992)
 8992   FORMAT(//1X,'PLEASE ENTER CURRENT TOP HEIGHT IN FEET:')
      ENDIF
      CALL ANSCHK(TH)
C-------ALLOW HURY SIMULATION TO BE DRIVEN BY AGE OR TOP HEIGHT
      WRITE(*,9997)
 9997 FORMAT(//1X,'WOULD YOU LIKE TO GROW THE HURY BY AGE',
     +          ' OR TOP HEIGHT?'//
     +          1X,'[A] FOR AGE'/
     +          1X,'[H] FOR TOP HEIGHT:')
      READ(*,9993) DRIVE
 9993 FORMAT(A3)
C-------ENTER HURY AGE IF DRIVING SIMULATION BY AGE
      IF(DRIVE.EQ.'A') THEN
        WRITE(*,9990)
 9990   FORMAT(//1X,'PLEASE ENTER CURRENT AGE IN MONTHS:')
        READ(*,9989) AGE
 9989   FORMAT(I4)
        SI=0.941390*TH*(1.0-EXP(-0.0564826*AGE))**(-1.75952)
      ELSE
        AGE=0
        SI=0
      ENDIF
      RETURN
      END
```

```
$DEBUG
      SUBROUTINE GROWN
C-------THIS SUBROUTINE GROWS A NEW STAND GIVEN THE INITIAL SPH
C-------AND SITE INDEX, OR GIVEN JUST THE INITIAL SPH
      INTEGER AGE,SPH
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     +     LDQO,LSPHO,AG,SPHO,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX
      CHARACTER OUT*10,DRIVE*3,UNITS*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPHO
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
      XSPH=SPH
C-------COMPUTE MAXIMUM DQ FOR CURRENT SPH
      MAX=LOG(MX)+7.6441-0.62305*LOG(XSPH)
C-------COMPUTE RELATIVE DENSITY LINE FOR COMMENCEMENT OF MORTALITY
      M1=LOG(MOD)+7.6441
      MORT=M1-0.62305*LOG(XSPH)
C-------SET INITIAL NUMBER OF STEMS PER HECTARE
      LSPHO=LOG(XSPH)
C-------IF DRIVING BY AGE, DETERMINE NEW TOP HEIGHT, DQ, AND SPH
      IF(DRIVE.EQ.'A') THEN
        DO 10 I=1,8
          AG=I*12
          TABLE(I,1)=AG
          TABLE(I,4)=1.062239*SI*(1.0-EXP(-0.0564826*AG))**1.75952
          TEST=2.2302-0.32707*LSPHO+1.09530*LOG(TABLE(I,4))
C------------ASSESS WHETHER HURY IS WITHIN COMPETITION MORTALITY ZONE,
C------------AND IF SO, SOLVE FOR NEW SPH GIVEN INITIAL SPH AND CURRENT
C------------TOP HEIGHT
          IF(TEST.GT.MORT) THEN
            CALL SYS
            TABLE(I,2)=SPHCUR
C--------------IF NOT WITHIN COMPETITION MORTALITY ZONE, SPH REMAINS
C--------------CONSTANT
          ELSE
            TABLE(I,2)=EXP(LSPHO)
          ENDIF
C------------COMPUTE NEW DQ FROM TOP HEIGHT AND SPH
          LDQ=2.2302-0.32707*LOG(TABLE(I,2))+1.0953*LOG(TABLE(I,4))
          TABLE(I,3)=EXP(LDQ)
   10   CONTINUE
```

```
C-------IF DRIVING BY HEIGHT GROWTH, GROW TOP HEIGHT AND DETERMINE
C-------NEW DQ AND SPH
      ELSE
        DO 11 I=2,15
          AG=I
          TABLE(I,4)=I
C------------ASSESS WHETHER HURY IS WITHIN COMPETITION MORTALITY ZONE,
C------------AND IF SO, SOLVE FOR NEW SPH GIVEN INITIAL SPH AND CURRENT
C------------TOP HEIGHT
          TEST=2.2302-0.32707*LSPH0+1.09530*LOG(TABLE(I,4))
          IF(TEST.GT.HORT) THEN
            CALL SYS
            TABLE(I,2)=SPHCUR
C--------------IF NOT WITHIN COMPETITION MORTALITY ZONE, SPH REMAINS
C--------------CONSTANT
          ELSE
            TABLE(I,2)=EXP(LSPH0)
          ENDIF
C------------COMPUTE NEW DQ FROM TOP HEIGHT AND SPH
          LDQ=2.2302-0.32707*LOG(TABLE(I,2))+1.0953*LOG(TABLE(I,4))
          TABLE(I,3)=EXP(LDQ)
   11   CONTINUE
      ENDIF
      RETURN
      END
```

```
SDEBUG
      SUBROUTINE GROWE
C-------THIS SUBROUTINE GROWS AN EXISTING HURY GIVEN ITS CURRENT
C-------SPH, TOP HEIGHT, AND SITE INDEX, OR GIVEN ONLY ITS CURRENT
C-------SPH AND TOP HEIGHT
      INTEGER AGE,SPH
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     +     LDQ0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX
      CHARACTER OUT*10,DRIVE*3,UNITS*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
      XSPH=SPH
C-------COMPUTE MAXIMUM DQ FOR CURRENT SPH
      MAX=LOG(MX)+7.6441-0.62305*LOG(XSPH)
C-------COMPUTE RELATIVE DENSITY LINE FOR COMMENCEMENT OF MORTALITY
      M1=LOG(MOD)+7.6441
      MORT=M1-0.62305*LOG(XSPH)
      Y0=-(LOG(MOD)-LOG(MX))
      LDQ0=2.2302-0.32707*LOG(XSPH)+1.0953*LOG(TH)
C-------SET INITIAL NUMBER OF STEMS PER HECTARE
      IF(LDQ0.LE.MORT) THEN
        LSPH0=LOG(XSPH)
      ELSEIF(LDQ0.GT.MAX) THEN
        RDO=EXP(LDQ0)/EXP(MAX-LOG(MX))
        WRITE(*,4545) RDO,MX
 4545   FORMAT(//1X,'THIS TOP HEIGHT AND DENSITY COMBINATION ',
     +          'INDICATES THAT'//3X,'RELATIVE DENSITY OF THIS HURY IS ',
     +          F5.2//3X,'BUT MAXIMUM IS CURRENTLY SET AT ',1X,F5.2//
     +          1X,'PLEASE CHECK EXISTING STAND CONDITIONS OR'/
     +          5X,'RESPECIFY THE MORTALITY MODEL !'//)
        STOP
      ELSE
        LSPH0=LOG(XSPH)+((1/B4)*LOG((MAX-LDQ0)/Y0))**(1/B5)
      ENDIF
C-------IF DRIVING BY AGE, DETERMINE NEW TOP HEIGHT, DQ, AND SPH
      IF(DRIVE.EQ.'A') THEN
        IAGE=AGE/12
        DO 10 I=IAGE,8
          AG=I*12
          TABLE(I,1)=AG
          TABLE(I,4)=1.062259*SI*(1.0-EXP(-0.0564826*AG))**1.75952
C-----------ASSESS WHETHER HURY IS WITHIN COMPETITION MORTALITY ZONE,
C-----------AND IF SO, SOLVE FOR NEW SPH GIVEN INITIAL SPH AND CURRENT
C-----------TOP HEIGHT
          TEST=2.2302-0.32707*LSPH0+1.09530*LOG(TABLE(I,4))
          IF(TEST.GT.MORT) THEN
            CALL SYS
            TABLE(I,2)=SPHCUR
```

```
C--------------IF NOT WITHIN COMPETITION MORTALITY ZONE, SPH REMAINS
C--------------CONSTANT
          ELSE
            TABLE(I,2)=EXP(LSPH0)
          ENDIF
C------------COMPUTE NEW DQ FROM TOP HEIGHT AND SPH
          LDQ=2.2302-0.32707*LOG(TABLE(I,2))+1.0953*LOG(TABLE(I,4))
          TABLE(I,3)=EXP(LDQ)
   10   CONTINUE
C-------IF DRIVING BY HEIGHT GROWTH, GROW TOP HEIGHT AND DETERMINE
C-------NEW DQ AND SPH
      ELSE
        IN=INT(TH)+1
        DO 11 I=IN,15
          AG=I
          TABLE(I,4)=I
C-----------ASSESS WHETHER HURY IS WITHIN COMPETITION MORTALITY ZONE,
C-----------AND IF SO, SOLVE FOR NEW SPH GIVEN INITIAL SPH AND CURRENT
C-----------TOP HEIGHT
          TEST=2.2302-0.32707*LSPH0+1.09530*LOG(TABLE(I,4))
          IF(TEST.GT.MORT) THEN
            CALL SYS
            TABLE(I,2)=SPHCUR
C--------------IF NOT WITHIN COMPETITION MORTALITY ZONE, SPH REMAINS
C--------------CONSTANT
          ELSE
            TABLE(I,2)=EXP(LSPH0)
          ENDIF
C-----------COMPUTE NEW DQ FROM TOP HEIGHT AND SPH
          LDQ=2.2302-0.32707*LOG(TABLE(I,2))+1.0953*LOG(TABLE(I,4))
          TABLE(I,3)=EXP(LDQ)
   11   CONTINUE
      ENDIF
      RETURN
      END
```

```
$DEBUG
      SUBROUTINE SYS
C-------THIS SUBROUTINE SOLVES FOR NEW SPH GIVEN THE NEW TOP
C-------HEIGHT OF THE HURY AND THE INITIAL SPH
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     +     LDO0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH
     +     SMX,MX
      INTEGER ISPH
      CHARACTER OUT*10,DRIVE*3,UNITS*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
C-------IF DRIVING BY AGE CONVERT TO YEARS FOR ARRAY SUBSCRIPTS
      IF(DRIVE.EQ.'A') THEN
        I=INT(AG/12)
      ELSE
        I=INT(AG)
      ENDIF
C-------RETRIEVE CURRENT TOP HEIGHT
      CTH=TABLE(I,4)
C-------SET PARAMETER ESTIMATES FOR DQ-TH-SPH CURVE
      A0=2.2302+1.09530*LOG(CTH)
      A1=-0.32707
C-------SET PARAMETER ESTIMATES FOR THE SELF-THINNING TRAJECTORY
      B0=7.6441+LOG(MX)
      B1=-0.62305
      B2=(LOG(MOD)-LOG(MX))+(SMX)*0.62305*LSPH0
      B3=LSPH0
C-------ESTABLISH TWO EXTREME STARTING VALUES BETWEEN WHICH THE NEW
C-------SPH MUST FALL, THAT IS, BETWEEN INITIAL SPH AND SOME MINIMUM
      XL(1)=LOG(100.0)
      XL(2)=LSPH0
C-------SOLVE FOR NEW SPH NUMERICALLY BY BISECTION METHOD
    5 DO 9 I=1,2
       FX(I)=-(A0+A1*XL(I)) + B0 + B1*XL(I) + B2*EXP(B4*(B3-XL(I))**B5)
    9 CONTINUE
      CRIT=FX(1)*FX(2)
      IF(CRIT.LE.0) THEN
        IF(XL(2)-XL(1).LT.0.001) GO TO 6
        TEMP=XL(1)
        TEMP2=(XL(1)+XL(2))/2
        XL(1)=TEMP2
      ELSE
        XL(2)=XL(1)
        XL(1)=(TEMP+XL(2))/2
      ENDIF
      GO TO 5
C-------STOP ALGORITHM WHEN MEET CONVERGENCE CRITERION AND COMPUTE SPH
    6 LSPH=(XL(1)+XL(2))/2
      SPHCUR=EXP(LSPH)
      RETURN
      END
```

```
$DEBUG
      SUBROUTINE NORM
C-------THIS SUBROUTINE ESTIMATES PARAMETERS OF THE NORMAL
C-------DISTRIBTUION GIVEN TOP HEIGHT, SPH, AND AGE OF THE HURY
      INTEGER AGE,GR(8),CLASS(25),YR(20)
      REAL A,SPH,AGEP,TH,DQ,LA,LDIFF,F1,F2,XPH,PI,BA,SIGMA,
     +       ST(25,8),PIP(6,3),TABLE(20,4),YIELD(20,5),STE(10,8)
      CHARACTER UNITS*3,DRIVE*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5,SMX,MX
      COMMON /YIE/YIELD
C-------INITIALIZE ARRAYS
      DO 60 I=1,8
        DO 60 J=1,6
          PIP(J,I)=0
   60 CONTINUE
      DO 61 I=1,25
        DO 61 J=1,8
          ST(I,J)=0
   61 CONTINUE
C-------READ TOP HEIGHT, SPH, AND DQ FOR EACH AGE
      IAGE=INT((AGE+12)/12)
      DO 789 IJ=IAGE,8
      AGEP=IJ*12
      SPH=TABLE(IJ,2)
      DQ=TABLE(IJ,3)
      TH=TABLE(IJ,4)
      PI=3.14159265
C-------COMPUTE BASAL AREA
      BA=SPH*(0.78539816*DQ**2)/10000
C-------PREDICT DMIN
      LA=2.640 - 0.57858*LOG(SPH) + 1.4182*LOG(TH)
      A=EXP(LA)*EXP(0.222/2)
C-------PREDICT DIFFERENCE BETWEEN ARITHMETIC MEAN AND QUADRATIC
C-------MEAN DIAMETER
      LDIFF = -11.693 + .000026501*SPH + 1.6931*LOG(TH) +
     +       2.4789*LOG(AGEP) - 0.05473*AGEP
      DBAR = DQ - EXP(LDIFF)*EXP(.2304/2)
C-------ASSUME DIFFERENCE BETWEEN ARITHMETIC MEAN DIAMETER AND
C-------MINIMUM DIAMETER REPRESENTS TWO STANDARD DEVIATIONS
      SIGMA=((DBAR-A)/2)**2
C-------COMPUTE STAND TABLE
        F1=(1/SQRT(2*PI*SIGMA))*EXP(-(1/(2*SIGMA))*(0.0-DBAR)**2)
        F2=(1/SQRT(2*PI*SIGMA))*EXP(-(1/(2*SIGMA))*(1.5-DBAR)**2)
        ST(1,IJ)=((F1+F2)*1.5/2)*SPH
      DO 44 J=2,25
        ZJ=J
        F1=(1/SQRT(2*PI*SIGMA))*EXP(-(1/(2*SIGMA))*(ZJ-0.5-DBAR)**2)
        F2=(1/SQRT(2*PI*SIGMA))*EXP(-(1/(2*SIGMA))*(ZJ+0.5-DBAR)**2)
        ST(J,IJ)=((F1+F2)/2)*SPH
   44 CONTINUE
```

```
C-------ADJUST THE DIAMETER DISTRIBUTION
      XPH=0
      DO 45 K=1,25
        ST(K,IJ)=ST(K,IJ)/50
        IF(ST(K,IJ).LT.0.5) ST(K,IJ)=0
        ST(K,IJ)=ST(K,IJ)*50
        XPH=XPH+ST(K,IJ)
   45 CONTINUE
      IF(XPH.LT.SPH) THEN
        DO 46 K=1,25
          ST(K,IJ)=ST(K,IJ) + (SPH-XPH)*(ST(K,IJ)/XPH)
   46   CONTINUE
      ELSEIF(XPH.GT.SPH) THEN
          ST(K,IJ)=ST(K,IJ) - (XPH-SPH)*(ST(K,IJ)/XPH)
      ENDIF
C-------TALLY NUMBER OF PIT PROPS DERIVED FROM STAND TABLES
      PIP(1,IJ)=0*ST(7,IJ)+0*ST(8,IJ)+0*ST(9,IJ)+0*ST(10,IJ)+
     +    0*ST(11,IJ)+0*ST(12,IJ)+0*ST(13,IJ)+0*ST(14,IJ)+
     +    1*ST(15,IJ)+1*ST(16,IJ)+1*ST(17,IJ)
      PIP(2,IJ)=0*ST(7,IJ)+0*ST(8,IJ)+0*ST(9,IJ)+0*ST(10,IJ)+
     +    0*ST(11,IJ)+0*ST(12,IJ)+1*ST(13,IJ)+1*ST(14,IJ)+
     +    0*ST(15,IJ)+0*ST(16,IJ)+0*ST(17,IJ)
      PIP(3,IJ)=0*ST(7,IJ)+0*ST(8,IJ)+0*ST(9,IJ)+0*ST(10,IJ)+
     +    0*ST(11,IJ)+1*ST(12,IJ)+1*ST(13,IJ)+1*ST(14,IJ)+
     +    0*ST(15,IJ)+0*ST(16,IJ)+1*ST(17,IJ)
      PIP(4,IJ)=0*ST(7,IJ)+0*ST(8,IJ)+0*ST(9,IJ)+0*ST(10,IJ)+
     +    1*ST(11,IJ)+1*ST(12,IJ)+0*ST(13,IJ)+1*ST(14,IJ)+
     +    1*ST(15,IJ)+2*ST(16,IJ)+0*ST(17,IJ)
      PIP(5,IJ)=0*ST(7,IJ)+1*ST(8,IJ)+1*ST(9,IJ)+2*ST(10,IJ)+
     +    1*ST(11,IJ)+0*ST(12,IJ)+1*ST(13,IJ)+0*ST(14,IJ)+
     +    1*ST(15,IJ)+1*ST(16,IJ)+0*ST(17,IJ)
      PIP(6,IJ)=1*ST(7,IJ)+0*ST(8,IJ)+1*ST(9,IJ)+1*ST(10,IJ)+
     +    1*ST(11,IJ)+1*ST(12,IJ)+0*ST(13,IJ)+0*ST(14,IJ)+
     +    1*ST(15,IJ)+0*ST(16,IJ)+2*ST(17,IJ)
  789 CONTINUE
C-------FILL IN GRADE, AGE, AND DBH CLASS INDICES
      DO 14 I=1,6
        GR(I)=I
   14 CONTINUE
      DO 15 LI=1,20
        YR(LI)=LI
   15 CONTINUE
      DO 16 LJ=1,25
        CLASS(LJ)=LJ
   16 CONTINUE
```

```
C-------OUPUT THE STAND TABLE AND PIT PROP DISTRIBUTION
      IF(UNITS.EQ.'M') THEN
         WRITE(2,2345) (CLASS(K),(ST(K,IJ),IJ=4,7),K=1,25),
     +                 (GR(L),(PIP(L,IJ),IJ=4,7),L=1,6)
 2345    FORMAT(///1X,'DBH DISTRIBUTION PER HA FOR THE HURY AT AGE:'//
     +       14X,'4',10X,'5',10X,'6',10X,'7  YRS'//
     +       25(1X,I3,' CM:',F8.0,3(3X,F8.0)/)
     +       ///1X,'PIT PROP GRADE DISTRIBUTION PER HA AT AGE:'//
     +       16X,'4',10X,'5',10X,'6',10X,'7  YRS'//
     +       6(1X,'GRADE ',I3,':',F8.0,3(3X,F8.0)/))
      ELSE
         DO 17 K=1,8
           STE(1,K)=(ST(1,K)+ST(2,K))/2.47
           STE(2,K)=(ST(3,K)+ST(4,K)+0.6*ST(5,K))/2.47
           STE(3,K)=(0.4*ST(5,K)+ST(6,K)+ST(7,K))/2.47
           STE(4,K)=(ST(8,K)+ST(9,K)+0.7*ST(10,K))/2.47
           STE(5,K)=(0.3*ST(10,K)+ST(11,K)+ST(12,K)+0.2*ST(13,K))/2.47
           STE(6,K)=(0.8*ST(13,K)+ST(14,K)+0.7*ST(15,K))/2.47
           STE(7,K)=(0.3*ST(15,K)+ST(16,K)+ST(17,K)+0.3*ST(18,K))/2.47
           STE(8,K)=(0.7*ST(18,K)+ST(19,K)+0.6*ST(20,K))/2.47
           STE(9,K)=(0.2*ST(20,K)+ST(21,K)+ST(22,K)+0.3*ST(23,K))/2.47
           STE(10,K)=(0.7*ST(23,K)+ST(24,K)+ST(25,K))/2.47
           DO 18 L=1,6
             PIP(L,K)=PIP(L,K)/2.47
   18      CONTINUE
   17    CONTINUE
         WRITE(2,2344) (CLASS(K),(STE(K,IJ),IJ=4,7),K=1,10),
     +                 (GR(L),(PIP(L,IJ),IJ=4,7),L=1,6)
 2344    FORMAT(///1X,'DBH DISTRIBUTION PER AC FOR THE HURY AT AGE:'//
     +       14X,'4',10X,'5',10X,'6',10X,'7  YRS'//
     +       10(1X,I3,' CM:',F8.0,3(3X,F8.0)/)
     +       ///1X,'PIT PROP GRADE DISTRIBUTION PER AC AT AGE:'//
     +       16X,'4',10X,'5',10X,'6',10X,'7  YRS'//
     +       6(1X,'GRADE ',I3,':',F8.0,3(3X,F8.0)/))
      ENDIF
C-------OUTPUT BIOMASS AND PIT PROP YIELDS TO FILE 'RUPEES.DAT'
      WRITE(4,4001) (YR(K),(YIELD(K,L),L=1,5),(PIP(J,K),J=1,6),K=1,8)
 4001 FORMAT(8(I3,5F11.4,6F7.0/))
      RETURN
      END
```

```
$DEBUG
      SUBROUTINE REPORT
C-------THIS SUBROUTINE WRITES THE FINAL YIELD REPORT TO THE SCREEN
C-------AND TO THE DESIGNATED OUTPUT FILE
      INTEGER I
      REAL CON1,CON2,CON3,SI,TH,TABLE(20,4),LDQ,MAX,M1,MOD,MORT,
     -     LDQ0,LSPH0,AG,SPH0,LSPH,XL(3),FX(3),SPHCUR,CRIT,CTH,
     +     SMX,MX,YIELD(20,5),S,BATH,ST,DEX
      CHARACTER OUT*10,DRIVE*3,UNITS*3
      COMMON /UN/UNITS,DRIVE
      COMMON /STAND/AGE,SPH,SI,TH,LSPH0
      COMMON /CONV/CON1,CON2,CON3
      COMMON /TAB/TABLE
      COMMON /SYST/SPHCUR
      COMMON /AGEC/AG
      COMMON /MOR/MOD,B4,B5
      COMMON /YIE/YIELD
C-------COMPUTE TOTAL PER HECTARE BIOMASS YIELDS BY COMPONENT
      DO 66 L=1,20
        IF(TABLE(L,4).NE.0) THEN
          S=TABLE(L,2)/1000
          BATH=TABLE(L,4)*TABLE(L,2)*(TABLE(L,3)**2)/10000
          ST=TABLE(L,2)*TABLE(L,4)/1000
          YIELD(L,2)=0.69631*(-0.302528+0.512966*S-0.307375*BATH)
          YIELD(L,3)=12.[illegible]-1.32515*S+0.241265*BATH+0.303987*ST
          YIELD(L,4)=-11.6343+2.31645*S+0.495973*BATH-0.610071*ST
          YIELD(L,1)=(0.30369/0.69631)*YIELD(L,2)
        ENDIF
   66 CONTINUE
C-------SET BIOMASS TO ZERO IF PREDICTION IS LESS THAN ZERO
      DO 67 I=1,20
        DO 68 J=1,4
          IF(YIELD(I,J).LT.0) YIELD(I,J)=0
   68   CONTINUE
        YIELD(I,5)=YIELD(I,1)+YIELD(I,2)+YIELD(I,3)+YIELD(I,4)
   67 CONTINUE
C-------DERIVE DBH DISTRIBUTION IF AGE DRIVEN SIMULATION
      IF(DRIVE.EQ.'A')THEN
        CALL NORM
      ENDIF
C-------CONVERT TO ENGLISH UNITS IF REQUESTED
      IF(UNITS.EQ.'E') THEN
        DO 30 IE=1,20
            TABLE(IE,2)=TABLE(IE,2)/2.47
            TABLE(IE,3)=TABLE(IE,3)/2.54
            TABLE(IE,4)=TABLE(IE,4)/.3048
   30   CONTINUE
      ENDIF
C-------SET UP HEADERS OF OUTPUT COLUMNS DEPENDING ON UNITS
      IF(DRIVE.EQ.'A') THEN
        IF(UNITS.EQ.'M') THEN
          WRITE(*,7778)
          WRITE(2,7778)
 7778     FORMAT(//1X,'SUMMARY OF HURY SIMULATION'//
     +          5X,'AGE',7X,'SPH',5X,'DQ, CM',3X,'TOP HEIGHT, M'//)
```

```
        ELSE
          WRITE(*,2778)
          WRITE(2,2778)
 2778     FORMAT(//1X,'SUMMARY OF HURY SIMULATION'//
     +            5X,'AGE',7X,'SPA',5X,'DQ, IN',3X,'TOP HEIGHT, FT'//)
        ENDIF
      ELSE
        IF(UNITS.EQ.'M') THEN
          WRITE(*,7779)
          WRITE(2,7779)
 7779     FORMAT(//1X,'SUMMARY OF HURY SIMULATION'//
     +            7X,'SPH',5X,'DQ, CM',3X,'TOP HEIGHT, M'//)
        ELSE
          WRITE(*,2779)
          WRITE(2,2779)
 2779     FORMAT(//1X,'SUMMARY OF HURY SIMULATION'//
     +            7X,'SPA',5X,'DQ, IN',3X,'TOP HEIGHT, FT'//)
        ENDIF
      ENDIF
C-------OUTPUT REPORT TO SCREEN
      DO 12 K=1,20
        IF(TABLE(K,4).NE.0) THEN
          IF(DRIVE.EQ.'A') THEN
            WRITE(*,7777) (TABLE(K,L),L=1,4)
            WRITE(2,7777) (TABLE(K,L),L=1,4)
 7777       FORMAT(5X,F4.0,5X,F6.0,4X,F4.1,7X,F4.1)
          ELSE
            WRITE(*,7776) (TABLE(K,L),L=2,4)
            WRITE(2,7776) (TABLE(K,L),L=2,4)
 7776       FORMAT(5X,F6.0,4X,F4.1,7X,F4.1)
          ENDIF
        ENDIF
   12 CONTINUE
C-------WRITE OUTPUT REPORT TO FILE
      IF(UNITS.EQ.'M') THEN
        IF(DRIVE.EQ.'A') THEN
          WRITE(2,2233)
 2233     FORMAT(///1X,'BIOMASS YIELDS IN METRIC TONS PER HECTARE'///
     +          22X,'W o o d y   M a t e r i a l'/
     +          27X,'-------------------------------------'/
     +          3X,'Age',7X,'Forage',8X,'< 2 cm',5X,'2 cm - 6.5 cm',
     +          5X,'> 6.5 cm',5X,'Total'//)
        ELSE
          WRITE(2,2234)
 2234     FORMAT(///1X,'BIOMASS YIELDS IN METRIC TONS PER HECTARE'///
     +          22X,'W o o d y   M a t e r i a l'/
     +          27X,'-------------------------------------'/
     +          1X,'Top Ht',5X,'Forage',8X,'< 2 cm',5X,'2 cm - 6.5 cm',
     +          5X,'> 6.5 cm',5X,'Total'//)
        ENDIF
```

```
      ELSE
        IF(DRIVE.EQ.'A') THEN
          WRITE(2,2333)
2333      FORMAT(///1X,'BIOMASS YIELDS IN TONS PER ACRE'///
     +          32X,'W o o d y   M a t e r i a l'/
     +          27X,'-------------------------------------'/
     +         3X,'Age',7X,'Forage',8X,'< 2 cm',5X,'2 cm - 6.5 cm',
     +         5X,'> 6.5 cm',5X,'Total'//)
        ELSE
          WRITE(2,2334)
2334      FORMAT(///1X,'BIOMASS YIELDS IN TONS PER ACRE'///
     +          32X,'W o o d y   M a t e r i a l'/
     +          27X,'-------------------------------------'/
     +         1X,'Top Ht',5X,'Forage',8X,'< 2 cm',5X,'2 cm - 6.5 cm',
     +         5X,'> 6.5 cm',5X,'Total'//)
        ENDIF
      ENDIF
      DO 22 K=1,20
        IF(YIELD(K,1).NE.0) THEN
          IF(UNITS.EQ.'M') THEN
            IF(DRIVE.EQ.'A') THEN
              DEX=TABLE(K,1)
            ELSE
              DEX=TABLE(K,4)
            ENDIF
            WRITE(2,5577) DEX,(YIELD(K,L),L=1,5)
5577        FORMAT(1X,F5.1,5(3X,F11.5))
          ELSE
            DO 24 I=1,5
              YIELD(K,I)=YIELD(K,I)*0.446275
  24        CONTINUE
            IF(DRIVE.EQ.'A') THEN
              DEX=TABLE(K,1)
            ELSE
              DEX=TABLE(K,4)
            ENDIF
            WRITE(2,5576) DEX,(YIELD(K,L),L=1,5)
5576        FORMAT(1X,F5.1,5(3X,F11.5))
          ENDIF
        ENDIF
  22  CONTINUE
      RETURN
      END
```

Hury Yield Model

Appendix D

YOUR HURY STARTS WITH THE FOLLOWING ATTRIBUTES:

STEMS PER HECTARE = 8000
TOP HEIGHT, METERS = .0
AGE = 0
SITE INDEX, METERS = 12.5

MORTALITY SPECIFICATIONS ARE:

MOD = .30
SMX = .00
B4 = -4.50
B5 = 1.00
MX = .80

DBH DISTRIBUTION PER HA FOR THE HURY AT AGE:

	4	5	6	7 YRS
1 CM:	0.	0.	0.	0.
2 CM:	0.	0.	0.	0.
3 CM:	29.	0.	0.	0.
4 CM:	84.	30.	0.	0.
5 CM:	198.	78.	44.	32.
6 CM:	376.	170.	100.	73.
7 CM:	576.	304.	192.	142.
8 CM:	712.	454.	312.	242.
9 CM:	711.	562.	430.	350.
10 CM:	574.	578.	501.	435.
11 CM:	373.	494.	495.	464.
12 CM:	196.	351.	414.	424.
13 CM:	83.	207.	293.	333.
14 CM:	28.	102.	176.	225.
15 CM:	0.	41.	89.	130.
16 CM:	0.	0.	38.	65.
17 CM:	0.	0.	0.	23.
18 CM:	0.	0.	0.	0.
19 CM:	0.	0.	0.	0.
20 CM:	0.	0.	0.	0.
21 CM:	0.	0.	0.	0.
22 CM:	0.	0.	0.	0.
23 CM:	0.	0.	0.	0.
24 CM:	0.	0.	0.	0.
25 CM:	0.	0.	0.	0.

PIT PROP GRADE DISTRIBUTION PER HA AT AGE:

	4	5	6	7 YRS
GRADE 1:	0.	41.	128.	222.
GRADE 2:	111.	309.	469.	558.
GRADE 3:	307.	660.	883.	1010.
GRADE 4:	597.	988.	1251.	1372.
GRADE 5:	3027.	2914.	2660.	2453.
GRADE 6:	2430.	2331.	2121.	2001.

SUMMARY OF HURY SIMULATION

AGE	SPH	DQ, CM	TOP HEIGHT, M
12.	8000.	2.1	3.8
24.	6330.	5.1	7.9
36.	4935.	7.5	10.4
48.	3939.	9.2	11.8
60.	3371.	10.4	12.5
72.	3085.	11.0	12.9
84.	2943.	11.4	13.1
96.	2872.	11.6	13.2

BIOMASS YIELDS IN METRIC TONS PER HECTARE

		Woody Material			
Age	Forage	< 2 cm	2 cm - 6.5 cm	> 6.5 cm	Total
12.0	2.45054	5.61868	14.69395	.00000	22.76318
24.0	12.37829	29.52776	50.46940	33.15563	126.03110
36.0	27.34717	62.70245	90.72411	107.07200	287.84580
48.0	37.33142	85.70929	116.08030	161.86190	401.83340
60.0	42.81114	98.15874	129.59680	192.43100	463.99760
72.0	45.61478	104.58700	137.59530	208.36510	496.16270
84.0	47.04873	107.87430	141.15900	216.53720	512.62070
96.0	47.73248	109.35720	142.78200	220.71810	521.03970

YOUR HURY STARTS WITH THE FOLLOWING ATTRIBUTES:

STEMS PER ACRE = 3239
TOP HEIGHT, FEET = .0
AGE = 0
SITE INDEX, FEET = 41.0

MORTALITY SPECIFICATIONS ARE:

MOD = .30
SMX = .00
B4 = -4.50
B5 = 1.00
MX = .80

DBH DISTRIBUTION PER AC FOR THE HURY AT AGE:

	4	5	6	7 YRS
1 IN:	0.	0.	0.	0.
2 IN:	94.	31.	11.	8.
3 IN:	418.	205.	126.	93.
4 IN:	739.	576.	443.	364.
5 IN:	106.	429.	453.	440.
6 IN:	38.	120.	191.	236.
7 IN:	0.	5.	26.	50.
8 IN:	0.	0.	0.	0.
9 IN:	0.	0.	0.	0.
10 IN:	0.	0.	0.	0.

PIT PROP GRADE DISTRIBUTION PER AC AT AGE:

	4	5	6	7 YRS
GRADE 1:	0.	17.	51.	90.
GRADE 2:	45.	125.	190.	226.
GRADE 3:	124.	237.	357.	409.
GRADE 4:	241.	400.	506.	555.
GRADE 5:	1225.	1180.	1078.	994.
GRADE 6:	984.	944.	860.	811.

SUMMARY OF NURY SIMULATION

AGE	SPA	DQ, IN	TOP HEIGHT, FT
12.	3239.	.3	11.5
24.	2563.	2.0	25.8
36.	1999.	2.9	34.0
48.	1596.	3.6	38.6
60.	1366.	4.1	41.0
72.	1250.	4.3	42.2
84.	1193.	4.5	42.9
96.	1164.	4.6	43.2

BIOMASS YIELDS IN TONS PER ACRE

		Woody Material			
Age	Forage	< 2 cm	2 cm - 6.5 cm	> 6.5 cm	Total
12.0	1.09314	2.50639	5.35528	.00900	10.15478
24.0	5.74335	13.16854	22.51177	14.77736	56.20102
36.0	12.19644	27.96438	40.46691	47.74078	123.36850
48.0	16.67175	38.22550	52.13243	72.17689	179.20760
60.0	19.09417	43.77972	58.28312	85.81408	206.94110
72.0	20.34579	46.64946	61.37824	92.92599	221.29950
84.0	20.98609	48.11758	62.57010	96.57424	228.64800
96.0	21.31489	48.87144	63.78729	98.44552	232.41910

BEST AVAILABLE DOCUMENT

APPENDIX E

PROGRAM HYMIRR.BAS: USE AND DOCUMENTATION

A. INTRODUCTION

HYMIRR.BAS is designed to combine HYM crop projections and user estimates of prices and costs to estimate internal rate of return. It was written in BASICA on an IBM-PC.

HYMIRR.BAS is interactive with a menu and instructions which guide the user through the process of entering prices and costa as well as changing them as part of sensitivity analysis. Any set of prices and costs can be stored in files. The user can re-use (overwrite) existing file names or save each new price or cost series under a different file name.

Once data entry is complete, a file called RUPEES.DAT created by HYM is combined with the price data to calculate the flow of revenues from the crop. The revenue and cost cash flows are submitted to an interactive search for the internal rate of return (IRR). This is the rate of return when the discounted costs equal the discounted revenues. The user is asked to specify the crop age for which the IRR is desired and then is asked for an IRR range and step which produces a table of discounted costs and revenues. By observing the convergence toward equality, the user can specify successive ranges and steps until an IRR is found at the level of accuracy deemed sufficient by the user.

After the IRR is found, the user can repeat the IRR search for other years or return to the main menu at which time prices and/or costs could be changed as part of a sensitivity analyses or the program may be terminated.

B. PROCEDURE:

- (Assumes Hard disk (drive C) and program disk on drive A)
- Press CTRL PRTSC whenever you with to get a printer copy of what will appear on your screen
- Press CAPS LOCK to guarantee upper case-capital-letters

1. RUN HYM on drive A to get a crop projection

   - Be sure to have a decimal point in the value entered for site index
   - In addition to the output file that you name, HYM created a file called RUPEES.DAT which is stored the diskette in drive A. This file contains the crop yield data used by program HYMIRR.BAS.

2. Change to drive C

3. Type BASICA

   a) Press F3 key to LOAD and type A:HYMIRR.BAS if you want hard copy press CTRL PRTSC

   b) Press F2 to RUN the program

      . HYMIRR will display the main menu - after an option is completed, this menu will reappear

      . If you choose to access an existing file or create a new file be sure to specify the appropriate disk drive - usually this would be drive A. Also, after using either edit option (options 3 or 6), you can save the edited data as a file.

      . When you price and cost data are set up, choose option 7 to analyze a crop projection.

      This option

      .. reads the RUPEES.DAT FILE
      .. displays the cash flows
      .. asks you to select a year for IRR calculations
      .. asks for an IRR search pattern which you can repeat as often as you with to achieve desired accuracy

      When done with an IRR search you can

      .. choose another year & calculate IRR again
      .. return to the main menu, change price or cost date (sensitivity analysis) and recalculate IRR
      .. quit by typing option 8 of main menu

4. To exit BASICA, type SYSTEM to get the C: prompt

   Repeat steps 1-4 to generate an analyses of a different crop

   An example of the procedure is illustrated on the following pages.

EXAMPLE

Assumes:

Hard disk - drive C and

program diskette in drive A

User responses are circled.

```
C:A:
A:HYM
A:\> echo off
```

```
Hury Yield Model
Version 1.0
```

```
Strike a key when ready . . .

PLEASE STATE THE NAME  OF YOUR OUTPUT FILE:
ZZZ.OUT

WOULD YOU PREFER ENGLISH OR METRIC UNITS?
TYPE (E) FOR ENGLISH OR (M) FOR METRIC:
M

WOULD YOU LIKE TO GROW A NEW OR AN EXISTING HURY?
(N) FOR NEW HURY
(E) FOR EXISTING HURY:
N

PLEASE ENTER INITIAL NUMBER OF STEMS PER HECTARE:
5000

WOULD YOU LIKE TO GROW THE HURY BY AGE OR TOP HEIGHT?
(A) FOR AGE
(H) FOR TOP HEIGHT:
A

PLEASE ENTER SITE INDEX IN METERS (BASE AGE % YRS OR 60 MONTHS):
10.  decimal point is critical
```

YOUR TRACT STARTS WITH THE FOLLOWING ATTRIBUTES:

```
STEMS PER HECTARE   =   5000
TOP HEIGHT, METERS  =     .0
AGE                 =      0
SITE INDEX, METERS  =   10.0
```

DO YOU WANT TO RESTART THE MODEL?
TYPE FOR YES
CALL FOR NO:

N

SUMMARY OF TRACT SIMULATION

AGE	SPH	DBH, CM	TOP HEIGHT, M
12.	5000.	1.9	3.1
24.	4607.	4.4	6.3
36.	4118.	6.2	8.3
48.	3823.	7.3	9.4
60.	3658.	7.9	10.0
72.	3568.	8.2	10.3
84.	3521.	8.3	10.5
96.	3496.	8.3	10.5

Stop Program terminated.

A:>
A:>
A:>TYPE [illegible] To get listing of the output file.

YOUR TRACT STARTS WITH THE FOLLOWING ATTRIBUTES:

```
STEMS PER HECTARE   =   5000
TOP HEIGHT, METERS  =     .0
AGE                 =      0
SITE INDEX, METERS  =   10.0
```

MORTALITY SPECIFICATIONS ARE:

```
MRD =    .30
SMX =    .00
B4  =  -4.50
B5  =   1.00
MX  =    .80
```

BEST AVAILABLE DOCUMENT

DBH DISTRIBUTION FOR THE HERD AT AGE:

	4	5	6	7 YRS
1 CM:	0.	0.	0.	0.
2 CM:	31.	0.	0.	0.
3 CM:	106.	64.	48.	41.
4 CM:	270.	171.	129.	110.
5 CM:	519.	356.	277.	237.
6 CM:	749.	576.	471.	412.
7 CM:	814.	725.	637.	578.
8 CM:	807.	709.	685.	655.
9 CM:	711.	540.	586.	600.
10 CM:	171.	319.	398.	444.
11 CM:	66.	147.	215.	265.
12 CM:	0.	52.	92.	128.
13 CM:	0.	0.	31.	50.
14 CM:	0.	0.	0.	0.
15 CM:	0.	0.	0.	0.
16 CM:	0.	0.	0.	0.
17 CM:	0.	0.	0.	0.
18 CM:	0.	0.	0.	0.
19 CM:	0.	0.	0.	0.
20 CM:	0.	0.	0.	0.
21 CM:	0.	0.	0.	0.
22 CM:	0.	0.	0.	0.
23 CM:	0.	0.	0.	0.
24 CM:	0.	0.	0.	0.
25 CM:	0.	0.	0.	0.

FEET LOGS GRADE DISTRIBUTION AT AGE:

	4	5	6	7 YRS
GRADE 1:	0.	0.	0.	0.
GRADE 2:	0.	0.	31.	50.
GRADE 3:	0.	52.	174.	177.
GRADE 4:	66.	199.	307.	393.
GRADE 5:	1526.	2034.	2313.	2457.
GRADE 6:	1483.	1783.	1928.	2015.

SUMMARY OF HERD SIMULATION

AGE	SPH	DBH, CM	TOP HEIGHT, M
12.	5000.	1.9	3.1
24.	4609.	4.1	6.3
36.	4118.	6.2	8.3
48.	3825.	7.3	9.4
60.	3658.	7.9	10.0
72.	3568.	8.2	10.3
84.	3521.	8.3	10.5
96.	3496.	8.5	10.5

BEST AVAILABLE DOCUMENT

BIOMASS YIELDS IN METRIC TONS PER HECTARE

Age	Forage	Woody Material < 2 cm	Woody Material 2 cm - 6.5 cm	Woody Material > 6.5 cm	Total
12.0	1.22762	2.81472	12.00073	.00000	16.04307
24.0	5.89603	13.51677	28.97729	6.16151	54.55080
36.0	12.84227	27.44516	49.38781	39.16974	130.84500
48.0	18.40726	42.20475	64.84144	67.18779	192.64130
60.0	21.86787	50.13887	74.25275	84.97182	231.23110
72.0	23.80027	54.57002	79.46124	94.99125	252.82280
84.0	24.82660	56.92322	82.21469	100.33650	264.30100
96.0	25.36001	58.14624	83.64283	103.11960	270.26870

End listing of ZZZ.OUT

This is the file created by HYM for use in HYMIRR.BAS

```
A: TYPE RUPEES.DAT
1    1.22762   2.81472   12.00073    .0000   16.0431   0.   0.   0
2    5.89603   13.51677  28.97729   6.1615   54.5508   0.   0.   .
3   12.84227   27.44516  49.38781  39.1697  130.8450   0.   0.   0
4   18.40726   42.20475  64.84144  67.1878  192.6413   0.   0.   .
5   21.86787   50.13887  74.25275  84.9718  231.2311   0.   0.   50
6   23.80027   54.57002  79.46124  94.9912  252.8228   0.  31.   12
7   24.82660   56.92322  82.21469 100.3365  264.3010   0.  50.   17
8   25.36000   58.14624  83.64283 103.1196  270.2687   0.  66.   22
```

You would ordinarily not want to get a listing of the contents of RUPEES.DAT

BEST AVAILABLE DOCUMENT

A:\C: change disk drives

C:\>BASICA → LOAD"A:HYMIRR.BAS [F3 key to load]
RUN [F2 key is RUN]

```
SELECT ONE OF THE FOLLOWING OPTIONS
   1. GET PRICES FROM AN EXISTING FILE
   2. CREATE A NEW PRICE FILE
   3. EDIT PRICES
   4. GET COSTS FROM EXISTING FILE
   5. CREATE NEW COST FILE
   6. EDIT COSTS
   7. CALCULATE IRR
   8. QUIT
? 1
ENTER NAME OF EXISTING PRICE FILE ? A:PRICE.DAT

SELECT ONE OF THE FOLLOWING OPTIONS
   1. GET PRICES FROM AN EXISTING FILE
   2. CREATE A NEW PRICE FILE
   3. EDIT PRICES
   4. GET COSTS FROM EXISTING FILE
   5. CREATE NEW COST FILE
   6. EDIT COSTS
   7. CALCULATE IRR
   8. QUIT
? 3

THE CURRENT PRICES ARE

1          FOLIAGE                    .1
2          WOODY 1 CM                 .15
3          WOODY 2 5.5CM              .25
4          GRADE 1 PRROUPS            30
5          GRADE 2 PRROUPS            30
6          GRADE 3 PRROUPS            27
7          GRADE 4 PRROUPS            16
8          GRADE 5 PRROUPS            9
9          GRADE 6 PRROUPS            5

TO CHANGE ANY PRICE, TYPE IT'S LINE NUMBER AND THE NEW PRICE
THE TYPE TWO ZEROS TO QUIT.
? 1,.005

THE NEW PRICES ARE

1          FOLIAGE                    .005
2          WOODY 1 CM                 .15
3          WOODY 2 5.5CM              .25
4          GRADE 1 PRROUPS            30
5          GRADE 2 PRROUPS            30
6          GRADE 3 PRROUPS            27
7          GRADE 4 PRROUPS            16
8          GRADE 5 PRROUPS            9
9          GRADE 6 PRROUPS            5

TO CHANGE ANY PRICE, TYPE IT'S LINE NUMBER AND THE NEW PRICE
THE TYPE TWO ZEROS TO QUIT.
? 0,0
```

BEST AVAILABLE DOCUMENT

YOUR CURRENT PRICES ARE

1	FOLIAGE	.005
2	WOODY 0-2.5CM	.005
3	WOODY 2-6.5CM	.25
4	GRADE 1 PRODUCTS	30
5	GRADE 2 PRODUCTS	30
6	GRADE 3 PRODUCTS	27
7	GRADE 4 PRODUCTS	16
8	GRADE 5 PRODUCTS	9
9	GRADE 6 PRODUCTS	5

TO CHANGE ANY PRICE, TYPE IT'S LINE NUMBER AND THE NEW PRICE
OR TYPE ONE ZERO TO QUIT.
? 0,0
DO YOU WANT TO WRITE TO A FILE , Y OR N ? Y
ENTER FILE NAME A:PRICE.DAT replaces original PRICE.DAT,

If you gave a different file name, say A:PR.DAT, you would have both on diskette as alternative choices in the future.

SELECT ONE OF THE FOLLOWING OPTIONS
1. GET PRICES FROM AN EXISTING FILE
2. CREATE A NEW PRICE FILE
3. EDIT PRICES
4. GET COSTS FROM EXISTING FILE
5. CREATE NEW COST FILE
6. EDIT COSTS
7. CALCULATE TOP
8. QUIT
? 1
ENTER NAME OF EXISTING PRICE FILE A:PRICE.DAT

SELECT ONE OF THE FOLLOWING OPTIONS
1. GET PRICES FROM AN EXISTING FILE
2. CREATE A NEW PRICE FILE
3. EDIT PRICES
4. GET COSTS FROM EXISTING FILE
5. CREATE NEW COST FILE
6. EDIT COSTS
7. CALCULATE TOP
8. QUIT
? 7

COST ITEMS BY YEAR

YEAR	COST	RETURN
0	1840.00	0.00
1	545.00	3[illegible].89
2	1060.00	[illegible]
3	242.00	[illegible]
4	242.00	4156.07
5	618.00	6[illegible]
6	500.00	5[illegible]42.46
7	600.00	73952.28
8	500.00	77[illegible].67

BEST AVAILABLE DOCUMENT

ENTER YEAR FOR WHICH YOUR WANT IRR TO BE CALCULATED
OR ENTER 1 TO QUIT

(7) WANT IRR FOR 7-th YEAR

ENTER RANGE AND INCREMENT OF IRR % TO TRY
OR ENTER ZERO TO QUIT

(0,100,5) INITIAL RANGE OF IRR VALUES

IRR %	DISC. COSTS	DISC. RETURNS
0.0	$5200.00	[illegible]
5.0	6006.12	[illegible]
10.0	5377.34	[illegible]
15.0	4870.72	[illegible]
20.0	4502.62	[illegible]
25.0	4190.25	[illegible]
30.0	3934.67	[illegible]
35.0	[illegible]	[illegible]
40.0	[illegible]	[illegible]
45.0	[illegible]	[illegible]
50.0	[illegible]	[illegible]
55.0	[illegible]	[illegible]
60.0	[illegible]	[illegible]
65.0	[illegible]	[illegible]
70.0	[illegible]	[illegible]
75.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
85.0	[illegible]	[illegible]
90.0	[illegible]	[illegible]
95.0	[illegible]	[illegible]
100.0	[illegible]	[illegible]

} IRR is between 55 & 60%

ENTER RANGE AND INCREMENT OF IRR % TO TRY
OR ENTER ZERO TO QUIT

(55,60,1) new IRR RANGE

IRR %	DISC. COSTS	DISC. RETURNS
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
58.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

} IRR IS BETWEEN 57 & 58 %

ENTER RANGE AND INCREMENT OF IRR % TO TRY
OR ENTER ZERO TO QUIT

(57,58,.1) New IRR RANGE

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IRR %	DISC. CASH	DISC. RETURNS
57.0	$116.35	$145.24
57.1	$114.40	$131.25
57.2	$112.46	$117.34 ← IRR ~ 57.2%
57.3	$110.52	$103.49
57.4	$108.57	$089.72
57.5	$106.67	$076.01
57.6	$104.74	$062.37
57.7	$102.83	$048.81
57.8	$100.92	$035.31
57.9	$099.01	$021.88
58.0	$097.12	$008.51

ENTER RANGE AND INCREMENT OF IRR % TO TRY
OR ENTER ZERO TO QUIT
? 0,0 NO NEED TO REFINE IRR FURTHER

IRR % DISC. CASH DISC. RETURNS

ENTER YEAR FOR WHICH CASH FLOW IRR TO BE CALCULATED
OR ENTER 0 TO QUIT
? 0 IF YOU WANTED TO CALCULATE IRR FOR A DIFFERENT YEAR, TYPE IT HERE

[illegible]
1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. CALCULATE IRR
8. QUIT
? 0
[illegible] — MESSAGE WHEN HYMIRR.BAS STOPS

[illegible] — TO LEAVE BASICA
C:

BEST AVAILABLE DOCUMENT

STRUCTURE OF FILE RUPEES.DAT

CREATED BY HYM

USED IN HYMIRR.BAS

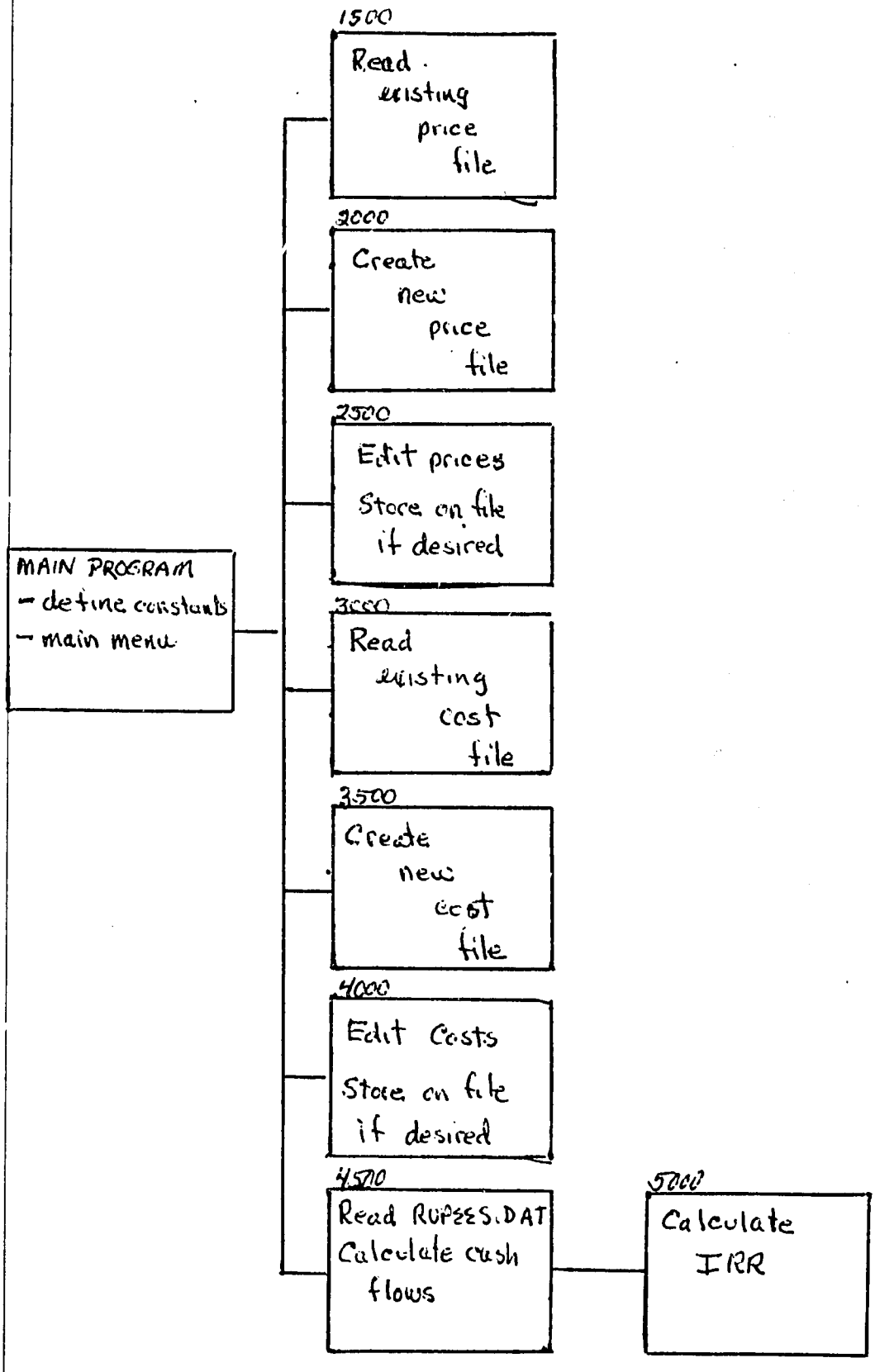
Each file record represents a year

Fields are;

1. Age, years
2. foliage biomass
3. woody biomass < 2.0 cm
4. woody biomass 2.0-6.5 cm
5. woody biomass > 6.5 cm
6. Total biomass
7. number of grade 1 pitprops
8. " 2 "
9. " 3 "
10. " 4 "
11. " 5 "
12. " 6 "

PROGRAM HYMIRR.BAS

Subroutine module relationships



VARIABLE DICTIONARY

ARRAYS

P(9)	stores prices of	1. foliage 2. woody < 2CM 3. woody 2-6.5CM 4 grade 1 pitprops 5 " 2 " 6 " 3 " 7 " 4 " 8 " 5 " 9 " 6 "
NS(9)	stores labels of products eg. 1 = foliage, 2 = woody < 2CM, ... whose prices are in array p	
S (3)	stores the 3 initial costs	
C$ (4)	stores labels of cost items	1 = seed, 2 = site prep 3 = land rent 4 = annual
WT (6)	stores unit weights, kg, of each pitprop grade	
Y(10)	vector of crop yields (1 = foliage; 2 = woody < 2CM, 3 = woody 2-6.5 cm, 4 = woody > 6.5CM, 5 = Grade 1 pitprops 6 = Grade 2 pitprops, ..., 10 = Grade 6 pitprops)	
C(9)	vector of costs, year 0, 1, ..., 10	
R(9)	vector of revenues, year 0, 1, ..., 10	

SIMPLE VARIABLES

C	menu selection choice
P$	file name
A$	menu selection choice
NYRS	no. of years in crop yield projection
PWT	weight of pitprops
QTY	weight of woody material > 6.5 CM not used as pitprops
IRR	interest rate
CSUM	discounted value of cost vector
RSUM	discounted value of revenue vector

```
LIST ."TIP11:"
10    HYMIRR.BAS                          3-23-88                    D. BRIGGS
100    READ LIST OF PRICE & COST IDENTIFIERS
105 DIM P(9),N$(9),S(3),C(10),R(10),C$(4),Y(10),WT(6)
110 FOR I=1 TO 9
115    READ N$(I)
120 NEXT I
125 FOR I=1 TO 4
130    READ C$(I)
135 NEXT I
140 DATA"FOLIAGE","WOODY <2 CM"
141 DATA"WOODY 2-6 CM","GRADE 1 PPROPS"
142 DATA"GRADE 2 PPROPS","GRADE 3 PPROPS"
143 DATA"GRADE 4 PPROPS","GRADE 5 PPROPS"
144 DATA "GRADE 6 PPROPS","SEED","SITE PREP"
145 DATA"LAND RENT","ANIMAL "
150 WT(1)=130.5/2.2
155 WT(2)=(85.72+96.62)/(2*2.2)
160 WT(3)=(70.45+86.50)/(2*2.2)
165 WT(4)=(57.45+67.41)/(2*2.2)
170 WT(5)=27.4/2.2
175 WT(6)=18.8/2.2
1000
1010    MAIN MENU
1020 CLS
1025 PRINT" SELECT ONE OF THE FOLLOWING OPTIONS"
1030 PRINT"    1. GET PRICES FROM AN EXISTING FILE"
1035 PRINT"    2. CREATE A NEW PRICE FILE"
1036 PRINT"    3. EDIT PRICES"
1037 PRINT"    4. GET COSTS FROM EXISTING FILE"
1038 PRINT"    5. CREATE NEW COST FILE"
1039 PRINT"    6. EDIT COSTS"
1040 PRINT"    7. CALCULATE IRR"
1041 PRINT"    8. QUIT"
1042 INPUT Y
1045 IF Y=0 AND Y>7 GOTO 1056
1050     PRINT" BAD CHOICE --- REENTER"
1055     GOTO 1025
1056 IF Y=8 GOTO 1095
1060 ON Y GOSUB 1500,2000,2500,3000,3500,4000,4500
1065 GOTO 1020
1095 STOP
5000
5005
5010    READ PRICE FILE
5011 INPUT"ENTER NAME OF EXISTING PRICE FILE ";P$
5012 OPEN P$ FOR INPUT AS #2
5025 FOR I=1 TO 9
5030    INPUT #2,N$(I),P(I)
5035 NEXT I
5037 CLOSE #2
5040 RETURN
```

labels used during file creation

pitprop weights for the 6 grades converted from lbs to kg

BEST AVAILABLE DOCUMENT

```
2000
2005 '
2010 'CREATE NEW PRICE FILE
2011 INPUT "ENTER NAME OF NEW PRICE FILE ",P$
2012 OPEN P$ FOR OUTPUT AS #2
2015 FOR I=1 TO  9
2025   PRINT "ENTER PRICE FOR ";N$(I);
2030   INPUT P(I)
2032    WRITE #2,N$(I),P(I)
2035 NEXT I
2045 CLOSE #2
2050 RETURN
2500 '
2505 '
2510 'PRICE EDIT
2515 PRINT
2520 PRINT" YOUR CURRENT PRICES ARE"
2525 PRINT
2530 FOR I=1 TO 9
2535   PRINT I,N$(I);TAB(40);P(I)
2540 NEXT I
2545 PRINT
2550 PRINT "TO CHANGE ANY PRICE, TYPE IT'S LINE NUMBER AND THE NEW PRIC
2555 PRINT "OR TYPE TWO ZEROS TO QUIT."
2560 INPUT I,P(I)
2570 IF I=0 GOTO 2580
2575 GOTO 2560
2580 INPUT"DO YOU WISH TO WRITE TO A FILE , Y OR N ";A$
2585 IF A$="Y" OR A$="N" GOTO 2600
2590   PRINT "INCORRECT - REENTER"
2595   GOTO 2580
2600 IF A$="N" GOTO 2640
2605 INPUT "ENTER FILE NAME ",P$
2615 OPEN P$ FOR OUTPUT AS #2
2620 FOR I=1 TO 9
2625   WRITE #2, N$(I),P(I)
2630 NEXT I
2635 CLOSE #2
2640 RETURN
2695   GOTO 2580
3000
3005
3010 'READ COST FILE
3015 INPUT"ENTER NAME OF EXISTING COST FILE ",P$
3020 OPEN P$ FOR INPUT AS #2
3035 FOR I=1 TO 3
3040   INPUT #2,C$(I),S(I)
3045 NEXT I
3050 FOR I=1 TO 10
3055   INPUT #2,C$(4),C(I)
3060 NEXT I
3070 CLOSE #2
3075 RETURN
```

BEST AVAILABLE DOCUMENT

```
3500 '
3505 '
3510 'CREATE NEW COST FILE
3515 INPUT "ENTER NAME OF NEW COST FILE ",P$
3520 OPEN P$ FOR OUTPUT AS #2
3525 PRINT
3530 PRINT "INITIAL COSTS/ACRE"
3535 FOR I=1 TO 3
3545   PRINT C$(I);TAB(15);
3550   INPUT S(I)
3560   WRITE #2,C$(I),S(I)
3565 NEXT I
3570 PRINT
3575 PRINT "ANNUAL COSTS/HECTARE"
3580 FOR I=1 TO 10
3590   PRINT"YEAR ";I;
3595   INPUT C(I)
3600   WRITE #2,C$(4),C(I)
3605 NEXT I
3615 CLOSE #2
3620 RETURN
4000
4005 '
4010 'COST EDIT
4015 PRINT
4020 PRINT "YOUR CURRENT INITIAL COSTS ARE"
4025 PRINT
4030 FOR I=1 TO 3
4035   PRINT I,C$(I),S(I)
4040 NEXT I
4045 PRINT "TO CHANGE ANY COST TYPE ITS LINE NUMBER & NEW COST"
4050 PRINT "OR TYPE ZEROS TO QUIT"
4055 INPUT I,S(I)
4060 IF I=0 GOTO 3500
4065 GOTO 4015
4070 PRINT
4075 PRINT"YOUR CURRENT ANNUAL COSTS ARE"
4080 PRINT"YEAR","COST"
4085 FOR I=1 TO 10
4090   PRINT I,C(I)
4095 NEXT I
4100 PRINT"TO CHANGE ANY COST TYPE ITS LINE NUMBER & NEW COST"
4105 PRINT "OR TYPE ZEROS TO QUIT"
4110 INPUT I,C(I)
4115 IF I=0 GOTO 4125
4120 GOTO 4075
4125 INPUT" DO YOU WANT TO WRITE TO A FILE, Y OR N ",A$
4130 IF A$="Y" OR A$="N" GOTO 4145
4135    PRINT"I'M CORRECT -  RESENTER"
4140    GOTO 4125
4145 IF A$="N" GOTO 4195
4150 INPUT"ENTER FILE NAME ",P$
4155 OPEN P$ FOR OUTPUT AS #2
4160 FOR I=1 TO 3
4165  WRITE #2,C$(I),S(I)
4170 NEXT I
4175 FOR I=1 TO 10
4180   WRITE #2, C$(4),C(I)
4185 NEXT I
4190 CLOSE #2
4195 RETURN
```

BEST AVAILABLE DOCUMENT

```
4500
4505
4510 'PROCESS TO GET REVENUE & COST VECTORS
4515 'SUM INITIAL COSTS -- YEAR ZERO
4520 C(0)=0
4525 FOR I=1 TO 3
4530   C(0)=C(0)+S(I)
4535 NEXT I
4540  READ ANNUAL CROP YIELDS AND MULTIPLY BY PRICES -- REVENUE VECTOR
4550 PRINT
4560 OPEN "A:KUPELS.DAT" FOR INPUT AS #2
4570   INPUT #2, NYRS,Y(1),Y(2),Y(3),Y(4),TOT,Y(5),Y(6),Y(7),Y(8),Y(9),Y(10)
4575   PW=0
4580   R(NYRS)=0
4585 ' PITPROPS
4590   FOR I= 5 TO 10
4595       R(NYRS)=R(NYRS)+Y(I)*P(I-1)
4600       PW=PW+Y(I)*W(I-5)
4605   NEXT I
4610 'COLLAGE, > 6CM, 2-6.5 CM
4615   FOR I=1 TO 3
4620       R(NYRS)=R(NYRS)+Y(I)*1000*P(I)
4625   NEXT I
4630   PRESENT 26.5 CM NOT USED FOR PITPROPS
4635   W1=TOT*1000-PW
4640   IF W1<0 THEN W1=0
4645   R(NYRS)=R(NYRS)+W1*P(3)
4650 IF NYRS>1 GOTO 4570
4651 PRINT
4652 PRINT"COST & RETURNS BY YEAR"
4653   PRINT        "YEAR          COST          RETURN"
4654 FOR I = 0 TO NYRS
4655   PRINT USING"####  ########.##  ########.##";I,C(I),R(I)
4660 NEXT I
4665 PRINT
4670 CLOSE #2
4675   END
4680 GOSUB 5000
4690 RETURN
```

Pitprop numbers times price of each
No. pitprops in cells 5-10 of Y
Prices in cells 4-9 of P
Pitprop weights also accumulated

convert metric tons to kg

subtract total weight of pitprops, kg from total biomass > 6.5cm, kg

— use price of 2-6.5cm material for this residual

BEST AVAILABLE DOCUMENT

```
5000
5005
5010    SEARCH FOR IRR
5015   GET IRR FOR ANY YEAR OF CASH FLOW
5020    IRR IS FOUND BY INTERACTIVE SEARCH
5025
5030 PRINT" ENTER YEAR FOR WHICH YOUR WANT IRR TO BE CALCULATED"
5035 PRINT" OR ENTER -1 TO QUIT"
5040 INPUT NYRS
5045 IF NYRS = -1 GOTO 5150
5050 PRINT "ENTER RANGE AND INCREMENT OF IRR % TO TRY"
5055 PRINT"OR ENTER ZEROS TO QUIT"
5060 INPUT IO,II,I2
5065 PRINT
5070 PRINT        " IRR %     DISC. COSTS  DISC. RETURNS"
5075 PRINT
5080 IF I2=0 GOTO 5050
5085    FOR IRR=IO TO II STEP I2
5090        RSUM=RCONVRS*(1+IRR/100)^NYRS
5095        CSUM=0
5100        FOR T=0 TO NYRS
5105          CSUM=CSUM+C(T)/(1+IRR/100)^T
5110     NEXT T
5115 PRINT USING"####.#   ##########.##   ##########.##";IRR,CSUM,RSUM
5120    NEXT IRR
5125 GOTO 5050
5150 RETURN
```

Interactive method to discover when discounted costs = discounted returns

Strategy:

apply a wide range and step initially to locate approximately when discountedcosts equal discounted returns

apply successively smaller range and step until desired accuracy is Achieved.

BEST AVAILABLE DOCUMENT