A MODEL OF THE STUBBLE REPLACEMENT DECISION FOR FLORIDA SUGARCANE GROWERS

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Sugarcane has been cultivated since at least 8000 B.C. (Barnes, p. 2) and today is grown throughout the world's tropical and subtropical regions. In Florida, sugarcane has been produced commercially since 1920 (Zepp). Before 1960, however, Florida sugar production was not significant; only three mills were in operation. With the ban on importation of Cuban sugar and the lifting of domestic sugarcane acreage restrictions in 1960, the industry grew rapidly.

In recent years Florida has been vying with Hawaii for the lead in domestic sugarcane production. Cane is also grown in Louisiana and Texas. Sugarcane accounts for approximately 42 percent of domestic raw sugar production and sugarbeets account for the remaining 58 percent. In 1975, Florida contributed 16 percent of domestic sugar production and slightly more than 1 percent of world production (Kidder and Lyrene).

Sugarcane grown in Florida can be harvested annually and yields a stalk containing about 0.3 pounds of raw sugar. Sugarcane is propagated vegetatively by planting sections of stalk known as seed cane, usually in the fall. The first crop, called plant cane, is harvested approximately 16 to 18 months later. It is a perennial plant which grows back each year after harvest from the portions of the stalk left under the ground. The subsequent crops are known as ratoon or stubble crops. Several factors generally combine to cause cane and sugar production to decline at a declining rate with subsequent ratoons. The stubble is typically replaced between two and five years after planting (Kidder and Lyrene).

The costs incurred when the stubble is replaced are the cost of plowing under the stubble, the cost of field preparation, and the cost of seed cane. Generally an additional opportunity cost is associated with the loss of revenue from one crop while the field is put to fallow; however, the cane can be grown in rotation with corn or vegetables, and rotation with rice appears to be a promising alternative (Alvarez et al.).

Sugarcane also can be replanted immediately without allowance for a fallow period. This practice, generally called "successive planting" in Florida, usually results in lower productivity but avoids the loss of revenue associated with fallowing. The main purpose of the fallow is to kill pests in the soil such as grubs and wireworms.

The sugarcane grower is faced with a tradeoff between declining sugar yield and the cost of replacement of the aging stubble including the cost of seed cane, the cost of plowing under the old stubble, cultivation, leveling, and replanting, and possibly the loss of revenue during a year of fallow plus any costs of fallow maintenance.

The grower's problem is analogous to the problem of replacement of industrial equipment subject to declining efficiency, which is treated in texts of finance and engineering economy (e.g., Mao, Grant et al.)[1] or, in agriculture, to the replacement decision for fruit orchards with declining yields. Sugarcane fields, however, cannot all be harvested when they are at individual optimum productivity because heavy capital requirements of raw sugar mills necessitate an extended harvest and grinding season. Thus, the replacement decision cannot be done on a field-by-field basis; rather, all fields belonging to a particular firm are interdependent and optimization must proceed at the firm level.

The replacement decision hinges on expected future revenues. Therefore, it is necessary to predict, in some manner, future yields for the current stubble crops as well as for the potential replacements. No fully satisfactory formal decision model is available.

The objectives of our article are to (1) review asset replacement theory and modify it for the stubble replacement decision, (2) propose a model to quantify the stubble replacement decision, and (3) empirically implement the model and demonstrate its use.

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[1]A succient review of the literature in this area is given by Rapp (1974, pp. I-1 to I-7). Additional work in this field of special interest to agriculturalists has been done by Faris, Burt (1963, 1965), Chisholm, Ward and Faris, Perrin, Perrin and Proctor, and Nelson and Purcell.

ASSET REPLACEMENT THEORY

According to Terborgh (p. 54):

> "A replacement analysis consists, obviously, of two separate and distinct operations. The first is the selection of the 'challenger', that is to say, the best unit or group of units now available for the replacement of the incumbent which we may call the 'defender'. The second is the determination of whether the challenge is valid, in other words, whether the defender is presently replaceable."

The first operation (i.e., selection of the challenger) is based mainly on Preinreich's model, commonly referred to as the Constant Chain Model. The challenger is specified as an infinite chain of identical replacements and hence is associated with "replacement policy." This concept is a modification of Hotelling's model in which a single asset is considered without replacement and which therefore is associated with "retirement policy."

Define a variable s to be the number of periods of remaining life until the asset is either retired or replaced; then the value of s associated with replacement will not in general be the same as that associated with retirement, as Chisholm has pointed out. For a "going concern" in which the operation associated with the asset is expected to continue indefinitely into the future, the replacement concept is most appropriate. Each challenger must be optimized with respect to s before it is compared with the defender and other challengers.

Preinreich's model was formulated initially as a continuous function, but Perrin (p. 64) offers a discrete analog which is more appropriate for the case of annual harvests typical of many agricultural problems. This model in slightly altered form can be given as

$$(1) \quad P(s, \infty) = \frac{1}{1-(1+r)^{-s}} \left[\sum_{t=1}^{s} (1+r)^{-t} R(t) + (1+r)^{-s} M(s) - K \right]$$

where

- $P(s, \infty)$ = net present value of an infinite stream of revenues from an asset type replaced every s years
- r = discount rate
- t = an integer year
- $R(t)$ = net revenue from the asset year in year t
- $M(s)$ = salvage value of the asset in year s
- K = initial cost of the asset.

Notice that the term in brackets in equation 1 is the net present value of a single link in the continuous chain and the factor outside the brackets converts it to an infinite chain.

In the sugarcane problem, salvage value is zero because the stubble is destroyed upon replacement. Thus, equation 1 can be simplified as

$$(2) \quad P_c = \frac{1}{1-(1+r)^{-s}} \left[\sum_{t=1}^{s} (1+r)^{-t} R(t) - K \right]$$

where it is understood that P_c is a function of s and pertains to an infinite stream of replacements.

Selection of the appropriate challenger therefore requires the present value for each challenger to be maximized with respect to s. This maximized present value can be denoted by P_c^*. Perrin (p. 64) offers a marginal criterion for maximization and Mao (p. 337-41) offers another, but as Perrin points out, "it is about as easy to evaluate the present value itself as to evaluate the marginal criterion" (p. 65). Furthermore, direct evaluation avoids the possibility of error as discussed by Perrin.

The analysis now can proceed to the second of Terborgh's operations, the determination of whether the challenge is valid.

In a going concern, the life of the defender can be extended one, two, or more years, but eventually the unit will be replaced by the best available challenger. If the best challenger currently available is c* and if we assume no technological advance, the replacement alternatives are (1) replace the defender with c* immediately or (2) extend the life of the defender by T years and then replace with c*. An appropriate selection criterion is to compare the net present values of the infinite revenue streams generated by each alternative. This criterion can be expressed as

$$(3) \quad \text{replace if } P_c^* > \sum_{t=1}^{T} (1+r)^{-t} E_t + (1+r)^{-T} P_c^*$$

where E_t is expected net revenue in year t if the defender's life is extended. This form shows that replacement is justified when the challenger's constant chain exceeds the defender's own constant chain in which the first link is the present value of net revenues obtained by extending the life of the defender T years. Thus, equation 3 can also be expressed

$$(4) \quad \text{replace if } P_c^* > \frac{1}{1-(1+r)^{-T}} \left[\sum_{t=1}^{T} (1+r)^{-t} E_t \right]$$

or

$$(5) \quad \text{replace if } P_c^* > P_{d(T)}$$

where $P_{d(T)}$ denotes the right side of equation 4.

If there is no salvage value and expected net revenue from the asset is declining such that $E_t > E_{t+1}$ for all t, we can show that

(6) $P_{d(1)} \geqslant P_{d(T)}$

for all T (Crane, p. 28). Now write

(7) $P_{d(1)} = \frac{1}{1-(1+r)^{-1}} [(1 + r)^{-1} E_1] = \frac{1}{r} E_1.$

Thus, the decision rule given by equation 4 reduces to

(8) replace if $P_{c*} > \frac{1}{r} E_1$

which is equivalent to

(9) replace if $A > E_1$

where A is given by

(10) $A = r P^*_c.$

The variable A can be interpreted as the "annualized" value of P^*_c where P^*_c is the principal of an annuity in perpetuity at interest rate r.

The decision rule given by equation 9 is the discrete analog of the replacement principle for the continuous case first proposed by Faris and later discussed by Perrin. Stated simply, the rule is to replace if the "average" net revenue from replacement exceeds the net revenue realized if the incumbent is kept another year. The rule has been employed by Perrin and Proctor in the replacement of apple orchards and by Grant et al. (p. 376-8) in the replacement of leaky gas mains.

ASSET INTERDEPENDENCE

A complicating factor relating to sugarcane production in Florida prevents direct application of equation 9. Cane growth takes place during the warm season from April to September. Sucrose content is low during this period, approximately 2 percent of gross weight. At the onset of cool weather, growth is retarded and sucrose accumulation in the stalk begins. Sucrose accumulates throughout the cool season for most varieties of cane. Thus, sugar yield is generally approaching its maximum in March when sucrose is about 10 percent of gross weight. A portion of sugarcane fields in Florida must be harvested before they have reached maximum yield to allow time for processing the whole crop through the (existing) sugar mills (Kidder and Lyrene). The reason is that the high capitalized value of sugar mills requires an extended harvest and grinding season to allow fixed costs to be averaged over a larger throughput (le Grand, p. 193).

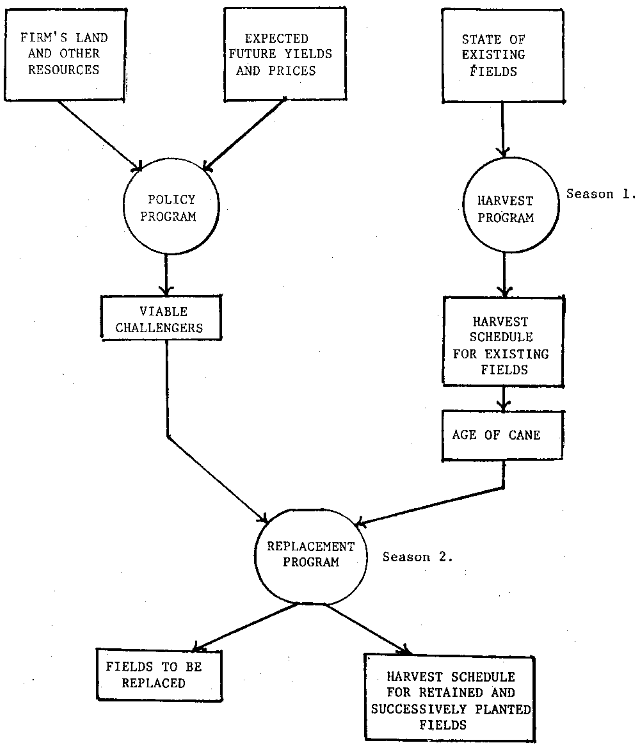
Arrangements are made between growers and processors whereby growers agree to deliver cane throughout the harvest period of November to March. Thus, the grower is constrained through mill quotas in the choice of when to harvest, and sugar yield depends directly on date of harvest. The annualized value of challengers for a particular field therefore cannot be computed without consideration of the harvest date for that field. Furthermore, the replacement decision cannot be made on a field-by-field basis; rather, all fields must be considered simultaneously to maximize total revenues to the firm subject to the mill delivery quotas.

OPTIMAL REPLACEMENT FOR SUGARCANE

The replacement decision can be reached with the aid of a series of three optimization models. The three models are called (1) policy program, (2) harvest program, and (3) replacement program. The programs are related as illustrated in Figure 1. This decision process takes place during September of Season 1.

The "policy program" is comparable to Terborgh's operation of selecting the best challenger. The program requires, as input, information describing the available resource set including types of land and varieties of

FIGURE 1. DIAGRAM OF THE THREE-STEP REPLACEMENT PROCEDURE



cane as well as forecasts of product and factor prices and of weather conditions. The policy program does not consider the state of cane actually growing during Season 1; rather, it addresses the question of how one would organize resources, which varieties would be grown on each type of land, how many years each would be grown, and during which period each would be harvested if one were to begin the operation free of the encumbrance of existing stools of cane and if all forecast variables actually were to attain expected values. The output of the policy program can be used to identify logical rotational patterns from which a number of "reasonable" challengers can be defined. An annualized value can be computed for each of these challengers and this information is required as input to the replacement program. The policy program can be viewed as a screening device to reduce the multitude of potential challengers to a manageable number.

In addition to the types of information input to the policy program, the harvest program requires information concerning the state of existing crops as of September, Season 1, which will permit prediction of yield for each field of cane for each potential harvest period. The harvest program then produces a revenue-maximizing harvest schedule. Though the harvest program is of considerable value to the cane grower in its own right, its principal purpose in our study is to date the harvest of a particular field of cane during Season 1 so that the age of cane as of September, Season 2, can be calculated. This information is valuable for the prediction of yield for each field during Season 2.

The replacement program compares the forecast revenues from each defending field and possible period of harvest with the annualized values for the appropriate challengers. The solution of the replacement program indicates which fields are to be left to ratoon in Season 2 and which are to be replaced to maximize revenue. In the case of fields to be replaced, the program identifies the replacing challenger. For those fields not replaced or those successively planted, the program generates an optimum harvest schedule in Season 2. The growers, however, will update this schedule as new weather information is received during the growing season.

Policy Program

The choice of which varieties to grow and for how long is similar to the choice of a crop rotation plan as discussed by Hildreth and Reiter (p. 144). However, whereas those authors concentrate on the determination of a rotation for a particular parcel of land from which an overall farm plan is inferred, our approach is to determine the overall farm plan for a typical year and infer the crop rotation from it.[2] For instance, if in the typical year the farm plan calls for a quarter of the land to be placed in each of fallow, plant cane, first ratoon cane, and second ratoon cane, one can infer that the crop cycle on any particular field begins with a fallow and that cane is grown for three harvests before the stubble is plowed under and the field is put to fallow again. The farm policy will be assumed to be repeated from year to year indefinitely until change in the cost structure or technological advance favors a new policy.

The probability that any actual farm would replicate the farm policy is effectively zero because the policy is based only on expected values, whereas actual crop performances vary considerably. The purpose of the harvest and replacement programs is to bridge the gap between policy and practice. The purpose of the policy program is merely to assign reasonable values to appropriate challengers which can be used as minimum standards of performance required of defending crops.

Traditionally, a fallow period has been introduced between each crop cycle. In recent years, however, it has become more popular to plant a short-term crop in the interim or to replant cane immediately. The latter practice is known as successive planting. When cane is successively planted, yields for the plant crop and all ratoon crops are expected to be lower than yields for cane that has been fallowed. Replacement is expected to occur at an earlier date for successively planted cane than for fallowed cane, but the cost of maintaining a fallow and the loss of a year's revenue are avoided.

The policy program does not consider alternative crops, but the successive cropping alternative is included. It is assumed that a given field can be successively planted only once before a fallow is required. In other words, a successively planted crop must be succeeded by a fallow but a fallowed crop can be succeeded either by a successive crop or by a fallow. A field is taken to be precisely 40 acres.

From the policy program various possible crop rotations can be identified. Each of these can be designated as a challenger to be compared with present crops. As the problem is currently specified, three types of crop rotations are permissible.

1. After a fallow, a variety of cane i is grown for a number of years I and is then succeded by a fallow and another crop cycle of I years and so forth.
2. After a fallow, a variety of cane i is grown for a number of years I and is fol-

[2] Walker (p. 6) has used such an approach.

lowed by a successive crop of variety i* which may or may not be the same as i. Variety i* is allowed to grow for J years. Then the rotation repeats.
3. Following a previous crop as a successive crop, variety i* is allowed to grow for J years. After a fallow, variety i is grown I years and the rotation is repeated.

The annualized value of a challenger c can be calculated as

(11) $A_c = g\,P_c^1$

where

P_c^1 = net present value of the first link in the constant chain of challenger c

$g = \frac{r}{1-(1+r)^{-s}}$ is the capital recovery factor

r = discount rate
s = the number of years in each link of the constant chain.

Harvest Program

The next step toward optimal replacement is an integer program to determine the optimal schedule for harvesting the current crop for all land classes. This program is most useful in September as an aid to harvest scheduling prior to the start of the harvest season; however, it can be recalculated at any time during the season if circumstances materially alter expected gross revenue per acre for any or all of the fields available for harvest during any or all of the remaining harvest periods. Because this program is concerned only with harvest scheduling, fields in fallow are disregarded.

The harvest program can be formulated mathematically as an integer programming problem. A mathematical statement of the problem is given by Crane (p. 50). The harvest program can be viewed conceptually as an assignment problem—the assignment of fields to harvest periods. Thus the mathematical formulation is a special case of the classic transportation problem and can be solved via linear programming yielding optimal integer solutions.[3]

The output of the harvest program will provide information on expected yield of the crop in the current year and expected age of the crop just prior to the start of the following season. This information is useful in the forecasting of yields and revenues for the following season.

Replacement Program

An optimal replacement pattern can be determined by forecasting expected revenues for all fields for the following year, including fields currently in fallow because the replacement decision has already been made for them, and comparing these figures with the annualized value of each of the available challengers.

The output of the replacement program is an optimal harvest schedule for the ensuing crop year. Mathematically, it is equivalent to the harvest program and thus is a special case of the transportation problem and can be solved via linear programming to yield optimal integer solutions.

This program completes the optimality routine and provides the information needed to decide whether a given field should be allowed to ration, or be used for a successively planted crop, or be fallow after being harvested in the current season.

IMPLEMENTING THE MODEL

The first step toward empirical implementation of the model is the prediction of yields from current and challenging crops. To achieve this end, yield prediction equations for cane grown in the Florida Everglades were estimated. A short disgression on sugarcane growth provides insight about the specification of these equations.

The production of sugar from a crop of sugarcane can be viewed as the result of two processes, (1) growth of cane and (2) accumulation of sucrose. The quantity of sugar commercially recoverable from a crop of cane at a given point in time is therefore given by

$$S_o = \lambda_o \times N_o$$

where

S_o = quantity of recoverable sugar
λ_o = a measure of accumulated sucrose
N_o = a measure of accumulated vegetative growth.

For sugarcane grown in the Florida Everglades, functional relationships for sucrose and vegetative growth were hypothesized on the basis of consultation with agronomists and sugarcane growers:[4]

(12) $\lambda_o = \lambda(V, G, M, X, Y, \lambda_1, H, O. B, T, W, Z)$,

(13) $N_o = \nu(V, G, M, X, Y, N_1, H, O. B. T, W, Z)$,

[3]The classic transportation problem is a special case of a network flow problem and as such can be solved efficiently through a number of algorithms. For further discuson see Hillier and Lieberman (p. 214-47).

[4]For a more complete discussion, see Crane.

where

V = variety of sugarcane
G = soil types
M = mode of harvesting
X = distance from Lake Okeechobee
Y = age of stubble
λ_1 = a measure of past performance with respect to sucrose production
N_1 = a measure of past performance with respect to vegetative growth
H = period of harvest
O = age of cane
B = freezing temperatures
T = growing season temperatures
W = solar radiation
Z = a composite of all relevant variables not specifically included in the model.

Florida sugarcane is grown primarily in the muck soil, mainly south and east of Lake Okeechobee. Some cane is grown in sandy muck south and southwest of the lake. Soil quality is inversely related to the distance from the lake and the lake also moderates low temperatures in the winter. Thus the distance from the lake serves as a proxy for both soil- and weather-related factors. The cane may be either hand or machine harvested. Machine-harvested cane generally yields less tonnage. The "age of cane" variable (O) refers to the number of days the current crop of cane has been growing (e.g., 10 months or 300 days).

Estimation of Prediction Equations

Data collection from 125 selected fields over the 1968 to 1976 seasons yielded 1025 observations. The sample included fields of six different firms and was chosen to represent adequately a cross-section of the production area. Examination of the data revealed that three soil types—custard apple muck, muck, and sand — adequately categorized the data. Furthermore, only certain varieties of cane are grown on a particular soil type. By discarding those soil type/variety combinations with few observations, we could identify nine soil variety classes.

A fixed effects model estimated for each equation allowed firm, soil variety, and mode of harvesting effects to act as both intercept shifters and slope shifters. All other variables were treated as covariates, entered as polynominals, and interacted with the class variables. Those interactions that were not "significant" ("t-ratio" of less than 2) were dropped from the model.

The resulting estimated equation for sucrose is given by

$$
\begin{array}{ll}
(14)\ \lambda_o = & 5.68 - 0.02\,D_2 + 0.94\,D_3 + 0.12\,D_4 + \\
& (5.39)\quad (-0.04)\quad (2.09)\quad (0.35) \\
& 2.37\,D_5 - 0.83\,D_6 - 0.47\,D_7 + 5.09\,D_8 - \\
& (2.82)\quad (-2.48)\quad (-0.61)\quad (4.02) \\
& 0.32\,D_9 + 1.46\,F_2 + 0.93\,F_3 + 1.51\,F_4 + \\
& (-1.08)\quad (3.18)\quad (3.83)\quad (7.32) \\
& 1.51\,F_5 + 0.75\,F_6 + 0.17767462\,Y + \\
& (7.89)\quad (3.10)\quad (2.41) \\
& 0.85\,M + 0.03211000\,X_z + \\
& (3.88)\quad (0.20) \\
& 0.00580883\,W_1 - 0.14396332\,B_m + \\
& (3.21)\qquad (-2.64) \\
& 0.01201211\,B_m^2 - 0.00035629\,B_m^3 + \\
& (1.89)\qquad (-2.11) \\
& 0.19628524\,H - 0.23961797\,D_3\dot{Y} - \\
& (9.69)\qquad (-2.67) \\
& 0.23314462\,D_4Y - 0.38954293\,D_5Y - \\
& (-1.87)\qquad (-2.53) \\
& 0.25215570\,D_7Y - 0.54865552\,D_8Y - \\
& (-1.10)\qquad (-2.97) \\
& 0.43917486\,D_3X_2 - 2.30190866\,D_8X_z - \\
& (-2.61)\qquad (-5.98) \\
& 0.94290504\,D_4B_m + 0.19268439\,D_4B_m^2 \\
& (-2.52)\qquad (2.45) \\
& -\ 0.00895522\,D_4B_m^3 - 0.25377194\,D_5H \\
& \quad (-2.31)\qquad (-2.52) \\
& -\ 0.17303305\,D_8H; \\
& \quad (-1.96)
\end{array}
$$

$$R^2 = 0.5178,\ \bar{R}^2 = 0.4842;\ MSE = 0.9724$$

where

D_i = 1 if the field is owned by the i^{th} firm, i=2, ..., 5
= 0 otherwise
F_j = 1 if the field is in the j^{th} soil variety class, j=2, ..., 9
= 0 otherwise
X_z = natural logrithm of the distance from the field to Lake Okeechobee measured in miles and rounded to the nearest half mile plus one
W_1 = solar radiation measured in average monthly Langley units for the five-month period April through August
B_m = the product of the number of accumulated hours between the temperatures of 28° F and 30° F and X_z
H = the period of harvest measured in two-week periods beginning October 1
M = 1 if the field was mechanically harvested in the current season
= 0 otherwise

and Y is defined as before. The numbers in parentheses are the estimated t-ratios.[5]

The impact of stubble age on net tons suggests an exponential specification for the variables Y in the net tons equation. The rate of yield decline differs among the soil variety groups. The resulting estimated net tons equation is

$$
\begin{aligned}
(15)\; N_o = {} & \underset{(0.49)}{0.00183680\,A} + \underset{(1.04)}{3.92\,F_2} + \underset{(1.93)}{4.28\,F_3} + \\
& \underset{(1.21)}{2.32\,F_4} + \underset{(3.18)}{5.54\,F_5} + \underset{(4.55)}{10.11\,F_6} - \underset{(-2.25)}{6.50\,U} + \\
& \underset{(4.94)}{39.89719081\,E_1} + \underset{(5.01)}{42.36686120\,E_2} + \\
& \underset{(3.03)}{20.72549548\,E_3} + \underset{(5.04)}{38.80605163\,E_4} + \\
& \underset{(3.25)}{28.89592754\,E_5} + \underset{(5.09)}{48.27300512\,E_6} + \\
& \underset{(4.73)}{48.29756186\,E_7} + \underset{(2.59)}{24.80319116\,E_8} + \\
& \underset{(2.06)}{34.40631495\,E_9} - \underset{(-2.37)}{5.17\,M_1} - \\
& \underset{(-5.53)}{0.60799543\,X} + \underset{(1.13)}{0.02836737\,W_a} + \\
& \underset{(4.15)}{0.70592518\,O} + \underset{(2.08)}{0.31254383\,H} - \\
& \underset{(-3.32)}{0.29841355\,B_y} - \underset{(-3.33)}{2.6946803\,D_8X} + \\
& \underset{(2.31)}{0.50716890\,D_3O};
\end{aligned}
$$

$$R^2 = .6747,\ \bar{R}^2 = .6495,\ MSE = 51.44$$

where

$$E_g = D_g e^{-(\varrho_g)Y}$$

and

$\varrho_1 = 0.352$
$\varrho_2 = 0.224$
$\varrho_3 = 0.255$
$\varrho_4 = 0.246$
$\varrho_5 = 0.097$
$\varrho_6 = 0.128$
$\varrho_7 = 0.140$
$\varrho_8 = 0.073$
$\varrho_9 = 0.320$

A = accumulated degree days for the period April through August where degree days for a single day are determined according to Allen et al. as $A_d = \max \{0, [)A \max - A \min)/2] - 60\}$ and A max and A min are highest and lowest temperatures recorded for the day in degrees Fahrenheit

M_1 = 1 if cane was mechanically harvested in the previous season
= 0 otherwise;

W_a = solar radiation measured in adjusted average monthly Langley units where the adjustment is $W_a = 0.08\,W_1 + .010\,W_2 + 0.12\,W_3 + 0.14\,W_4 + 0.16\,W_5$ and W_1 through W_5 are average monthly Langley units for the months April through August, respectively (see Allen et al.)

O = age of the cane expressed as the number of two-week periods prior to September 1

B_y = accumulated number of hours below 32° F in the period beginning two weeks after planting or harvesting and running through the end of the season in which the cane was planted or harvested

U = 1 if the field was successively planted
= 0 otherwise

and D_g, X and Y are defined as before. The figures in parentheses are ratios of the estimated parameters to their asymptotic standard errors (Gallant, p. 80).

DEMONSTRATION OF THE MODEL

A hypothetical 55-field firm was assembled.[6] The firm's fields were chosen to represent a cross-section of the Everglades area with respect to soil type and distance from the lake and thus the firm bears little resemblance to an actual firm. The soil type and distance from the lake for the 55 fields are shown in Table 1. The soil variety combinations to be considered by the firm are listed in Table 2.

TABLE 1. LAND CLASSIFICATION FOR HYPOTHETICAL FIRM.

Land class	Soil type	Distance of land class boundaries from Lake Okeechobee	Average distance of fields from Lake Okeechobee	Number of fields
		---Miles---		
1	custard apple	≤2	0.857	8
2	standard muck	≤2	1.417	6
3	standard muck	2--5	4.000	8
4	standard muck	5--10	7.375	12
5	standard muck	>10	15.643	14
6	sand	≤2	1.786	7

TABLE 2. VARIETY/SOIL TYPE GROUPS TO BE CONSIDERED.

Variety	Maturity characteristic	Soil type
CP 63-588	mid-season	standard muck
Cl 41-223	late	custard apple
Cl 41-223	late	standard muck
CP 56-59	mid-season	standard muck
Cl 54-378	early	standard muck
CP 57-603	late	custard apple
CP 57-603	late	standard muck
Cl 41-191	late	sand
Cl 49-198	early/mid	standard muck

[5]The Relatively poor "fit" of equation 14 is due in part to the lack of understanding of the nature of the sucrose accumulation process.

[6]Firms that participated in the survey wanted their anonymity protected; thus the model could not be utilized for a particular firm and the results published.

Production on the firm's 55 fields is considered for three seasons, 0 through 2. The decision process is being conducted during September of Season 1. The firm must decide when each of the fields should be harvested during the current season and must also decide which of the fields are to be replaced on the basis of projections of performance in Season 2, if the fields are allowed to ratoon. The current fields in Season 0 are assigned a representative distribution of year of crop cycle, prior mode of harvest, and date of last harvest.

Solution to the Policy Program

Interacting the nine soil variety combinations with distance from the lake yields 27 combinations of soil variety/distance from the lake, hereafter called options. Each combination is allowed to ratoon at most five times. Each field can be fallowed or successively planted and can be harvested in one of the nine two-week harvest periods. A summary of the solution to the policy program for the hypothetical firm is given in Table 3.

Associated with the options in the policy solution is an optimal harvest schedule. The harvest schedule follows a logical pattern of harvesting the early-maturing varieties early and the late-maturing varieties late in the harvest season. For the late-maturing varieties, plant cane is harvested last, first ratoon next last, etc., as is consistent with *a priori* expectations.

TABLE 3. SOLUTION TO THE FIRM'S POLICY PROGRAM.

Option	Land Class	Variety
Ø02	1	CP 57-603
Ø07	2	CP 57-603
Ø13	3	CP 57-603
Ø18	4	Cl 54-378
Ø23	5	CP 56-59
Ø24	5	Cl 54-378
Ø27	6	Cl 49-198

TABLE 4. ANNUALIZED PER ACRE VALUES FOR 14 CHALLENGERS.

Challenger	Variety	Land class	First year fallow	Annualized value
				------Dollars-------
CH1	CP 57-603	1	yes	789
CH2	Cp 57-603	1	no	855
CH3	CP 57-603	2	yes	730
CH4	CP 57-603	2	no	776
CH5	CP 57-603	3	yes	713
CH6	CP 57-603	3	no	768
CH7	Cl 54-378	4	yes	514
CH8	Cl 54-378	4	no	544
CH9	CP 56-59	5	yes	481
CH10	CP 56-59	5	no	506
CH11	Cl 54-378	5	yes	454
CH12	Cl 54-378	5	no	488
CH13	Cl 41-191	6	yes	477
CH14	Cl 41-191	6	no	512

For all seven options in the solution, successive planting of cane is used. This gives rise to two challengers associated with each option. For example, one challenger begins with a fallow, then one crop cycle of three years followed by a successively planted crop cycle of two years. The other challenger begins with a successively planted crop of two years, then a fallow, followed by a three-year crop cycle. Each of these challengers represents a six-year rotation.

The annualized values of the 14 challengers, computed with a discount rate of 15 percent, are listed in Table 4.

Solution to the Harvest Program

Of the 55 fields, 47 are assumed to be not in fallow and thus must be harvested during the current season (Season 1). Table 5 is the optimal harvest schedule.

TABLE 5. HARVEST SCHEDULE OF 47 FIELDS FOR FIRM F IN SEASON 1.

Harvest period								
4	5	6	7	8	9	10	11	12
F321 (762)[a]	F326 (554)	F330 (719)	F328 (593)	F315 (513)	F302 (590)	F301 (865)	F311 (839)	F307 (1109)
F323 (797)	F350 (775)	F343 (619)	F329 (524)	F319 (780)	F303 (528)	F304 (655)	F313 (922)	F312 (1174)
F325 (663)	F351 (652)	F344 (511)	F340 (515)	F320 (732)	F305 (600)	F316 (779)	F318 (876)	F327 (763)
F352 (572)	F353 (608)	F345 (373)	F349 (671)	F335 (601)	F306 (610)	F317 (742)	F324 (820)	F339 (736)
			F354 (667)	F336 (538)	F309 (595)	F331 (877)	F332 (726)	F341 (735)
				F337 (529)	F310 (606)	F338 (685)	F342 (861)	F346 (590)

[a]Figures in parentheses are expected revenues per acre in dollars

Solution to the Replacement Program

To decide whether to replace a particular field during the current season, the firm must project the revenue expected from each of the 55 fields for each of the nine available harvest periods if the cane is allowed to ratoon in the following season. These values are then compared with the annualized values of the 14 challengers in accordance with equation 11 to find the combination of defenders and challengers which will maximize expected revenues in the following season.

The fields to be replaced and the challengers which are to replace them are listed in Table 6. Notice that of the 22 fields to be replaced, 19 are replaced with successive crops (even-numbered challengers). All fields replaced are those with aged stubble (at least 2 years old) or planted with lower-yielding varieties. In no case was plant cane replaced.

TABLE 6. LIST OF FIELDS TO BE REPLACED AND REPLACING CHALLENGERS.

Field	Challenger	Field	Challenger
F302	CH1	F318	CH6
F303	CH1	F319	CH6
F301	CH2	F320	CH6
F304	CH2	F326	CH8
F305	CH2	F327	CH8
F306	CH2	F336	CH10
F310	CH3	F337	CH10
F309	CH4	F340	CH10
F315	CH6	F344	CH10
F316	CH6	F345	CH10
F317	CH6	F346	CH10

CONCLUDING COMMENTS

The key to the usefulness of the proposed model is the forecasting of future yields of both potential replacements and incumbents. The yield prediction equations we describe leave room for improvement, which could be achieved by combining growers' judgment with statistically based predictions to generate forecasts.

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