Sugar Cane C

1977

A CONCEPTUAL MODEL OF THE STUBBLE REPLACEMENT DECISION FOR FLORIDA SUGARCANE GROWERS

Donald R. Crane, Jr.
and
Thomas H. Spreen

The authors, Donald R. Crane is Project Development Officer, Agricultural Cooperative Development International and Thomas H. Spreen is Assistant Professor, Food and Resource Economics Department, University of Florida.

Presented at AAEA meetings, Pullman, July 29-Aug. 1, 1979.

A CONCEPTUAL MODEL OF THE STUBBLE REPLACEMENT DECISION FOR FLORIDA SUGARCANE GROWERS

Donald R. Crane and Thomas H. Spreen

ABSTRACT

Sugarcane is a perennial plant which grows back each year after harvest. A number of factors cause yields to decline as the stubble ages. The stubble can be viewed as an asset with declining productivity. Asset replacement theory is reviewed and a model is proposed to quantify the replacement decision.

A CONCEPTUAL MODEL OF THE STUBBLE REPLACEMENT DECISION FOR FLORIDA SUGARCANE GROWERS

Introduction

Sugarcane has been cultivated since at least 8000 B.C. (Barnes, 1974, p.2) and today is widely grown throughout the world's tropical and simi-tropical regions. In Florida, sugarcane has been produced commercially since 1920 (Zepp, 1976). Prior to 1960, however, Florida sugar production was not significant with only three mills in operation. With the ban on importation of Cuban sugar and 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 with sugarbeets accounting for the remaining 58 percent. In 1975, Florida contributed 16 percent of domestic sugar production and slightly over 1 percent of world production (Kidder and Lyrene, 1976).

Sugarcane grown in Florida can be harvested annually yielding 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 fall. The first crop is harvested approximately sixteen to eighteen months later and is called plant cane. 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. A number of factors generally combine to cause cane and sugar production to decline at a declining rate with subsequent ratoons. The stubble is normally replaced between three and ten years after planting (Kidder and Lyrene, 1976).

A number of costs are incurred when the stubble is replaced. They include the cost of plowing under the stubble, the cost of field preparation and the cost of seed cane. There is generally an additional opportunity cost associated with the loss of revenue from one crop while the field is put to fallow, however, the cane may be grown in rotation with corn or vegetables and rotation with rice appears to be a promising alternative (Alvarez et al., 1979).

Sugarcane may also be immediately replanted without allowance for a fallow period. This latter 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 (Mao, 1969 and Grant et al., 1976, for instance),[1/] or in agriculture, to the replacement decision for fruit orchards with declining yields. In contrast to fruit orchards, however, sugarcane fields can not all be harvested when they are at individual optimum productivities. This is because heavy capital requirements for raw sugar mills necessitate an extended harvest and grinding season. Thus, the fields of a particular firm are interdependent and optimization which depends upon harvest scheduling must proceed at the firm level.

The replacement decision hinges on expected future revenues and, therefore, it is necessary to predict, in some manner, future productivity for the existing stubble crops as well as for the potential replacements. No fully satisfactory, formal decision model currently exists.

The objectives of this paper are twofold. First asset replacement theory is reviewed and modified for the stubble replacement decision. Second, a three-step procedure is proposed to quantify the stubble replacement decision.

Asset Replacement Theory

According to Terborgh:

> 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 (Terborgh, 1949, p.54).

The first operation (i.e., selection of the challenger) relies heavily upon Preinreich's model (Preinreich, 1940) 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 (Hotelling, 1925) 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 (1966) 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 initially formulated as a continuous function, but Perrin (1972, 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 may be given as:

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

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 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 (1) is the net present value of a single link in the continuous chain and the factor outside the brackets converts this to an infinite chain.

In the sugarcane problem, salvage value is zero since the stubble is destroyed upon replacement. Thus, equation (1) may be simplified as:

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

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 may be denoted by P_c^*. Perrin (1972, p.64) offers a marginal criterion for maximization and Mao (1969, p.337-341), offers another, but as Perrin points out "it is about as easy to evaluate the present value itself as to evaluate the marginal criterion" (1972, p.65). Furthermore, direct evaluation avoids the possibility of error as discussed by Perrin (1972).

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

In a going concern, the life of the defender may be extended one, two, or more years, but eventually it will be replaced by the best available challenger. If the best challenger currently available is c* and assuming no technological advance then the replacement alternatives are: (i) replace the defender with c* immediately, or (ii) 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 may be expressed as:

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

where E_t is expected net revenue in year t if the defender's life is extended. In this form it is seen 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, (3) may also be expressed

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

or

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

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

In the case where there is no salvage value and expected net revenue from the asset is declining such that $E_t > E_{t+1}$ for all t,

$$(6) \qquad P_{d(1)} \geq P_{d(T)}$$

for all T. To show this write

$$(7) \qquad P_{d(T)} = \frac{1}{1-(1+r)^{-T}} \left[\sum_{t=1}^{T} (1+r)^{-t} E_t \right]$$

$$\leq \frac{1}{1-(1+r)^{-T}} \left[\sum_{t=1}^{T} (1+r)^{-t} E_1 \right]$$

since $E_t \leq E_1$ for all t. This may be rewritten as

$$(8) \qquad P_{d(T)} \leq \frac{E_1}{1-(1+r)^{-T}} \left[\sum_{t=1}^{T} (1+r)^{-t} \right]$$

However the term in brackets is a finite geometric series, thus

$$(9) \qquad \sum_{t=1}^{T} (1+r)^{-t} = \frac{\frac{1}{1+r} - \left(\frac{1}{1+r}\right)^{T+1}}{1 - \frac{1}{1+r}} = \frac{1-(1+r)^{-T}}{r} .$$

Therefore, (8) reduces to

$$(10) \qquad P_{d(T)} \leq \frac{E_1}{1-(1+r)^{-T}} \left[\frac{1-(1+r)^{-T}}{r}\right] = \frac{1}{r} E_1 .$$

Now write

$$(11) \qquad P_{d(1)} = \frac{1}{1-(1+r)^{-1}} \left[(1+r)^{-1} E_1 \right] = \frac{1}{r} E_1 .$$

Comparison of (10) and (11) yields (6). This result insures that annual application of (4) with T=1 will produce an optimal replacement policy, that is replace if

$$(12) \qquad P_c^* > \frac{1}{r} E_1$$

which is equivalent to

(13) replace if $A > E_1$

where A is given by

$$(14) \qquad A = r\,P_c^* \,.$$

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

Substituting from (2) for P_c^* in (14) gives

$$(15) \qquad A = r\,P_c^* = \frac{r}{1-(1+r)^{-s}} \left[\sum_{t=1}^{s} (1+r)^{-t} R(t) - K \right]$$

where the term outside the brackets on the right hand side of (15) is known as the "capital recovery factor".[2/]

Decision rule (13), used by Perrin and Proctor (1974) in the discussion of replacement of apple orchards and by Grant (1976, pp.376-378) in the replacement of leaky gas mains, is convenient and easily applied. The preceding presentation, however, is the first explicit derivation of the decision rule showing the equivalence to the standard investment criterion of selecting the highest net present value of alternative revenue streams, known to the authors.

Asset Interdependence

There is a complicating factor relating to sugarcane production in Florida which prevents direct application of equation (13). Cane growth takes place during the warm season from April to September while sucrose content is low during this period. When cool weather arrives, 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. 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, 1976). This is because the high capitalized value of sugar mills requires an extended harvest and grinding season in order that fixed costs be averaged over a larger throughput (le Grand, p.193).

Arrangements are made between growers and processors in which 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 upon date of harvest. Therefore, the annualized value of challengers for a particular field cannot be computed without considering date of harvest for that field. Furthermore, the replacement decision cannot be made on a field by field basis, rather all fields must be considered simultaneously in order to maximize total revenues to the firm subject to the mill delivery quotas.

Optimal Replacement for Sugarcane

The replacement decision may be reached with the aid of a series of three optimization models. The three models are called: (i) policy program, (ii) harvest program, and (iii) replacement program. These 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. This program requires, as input, information describing the available resource set including types of land and varieties of cane as well as forecasts of product and factor prices and of weather conditions[3/]. 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

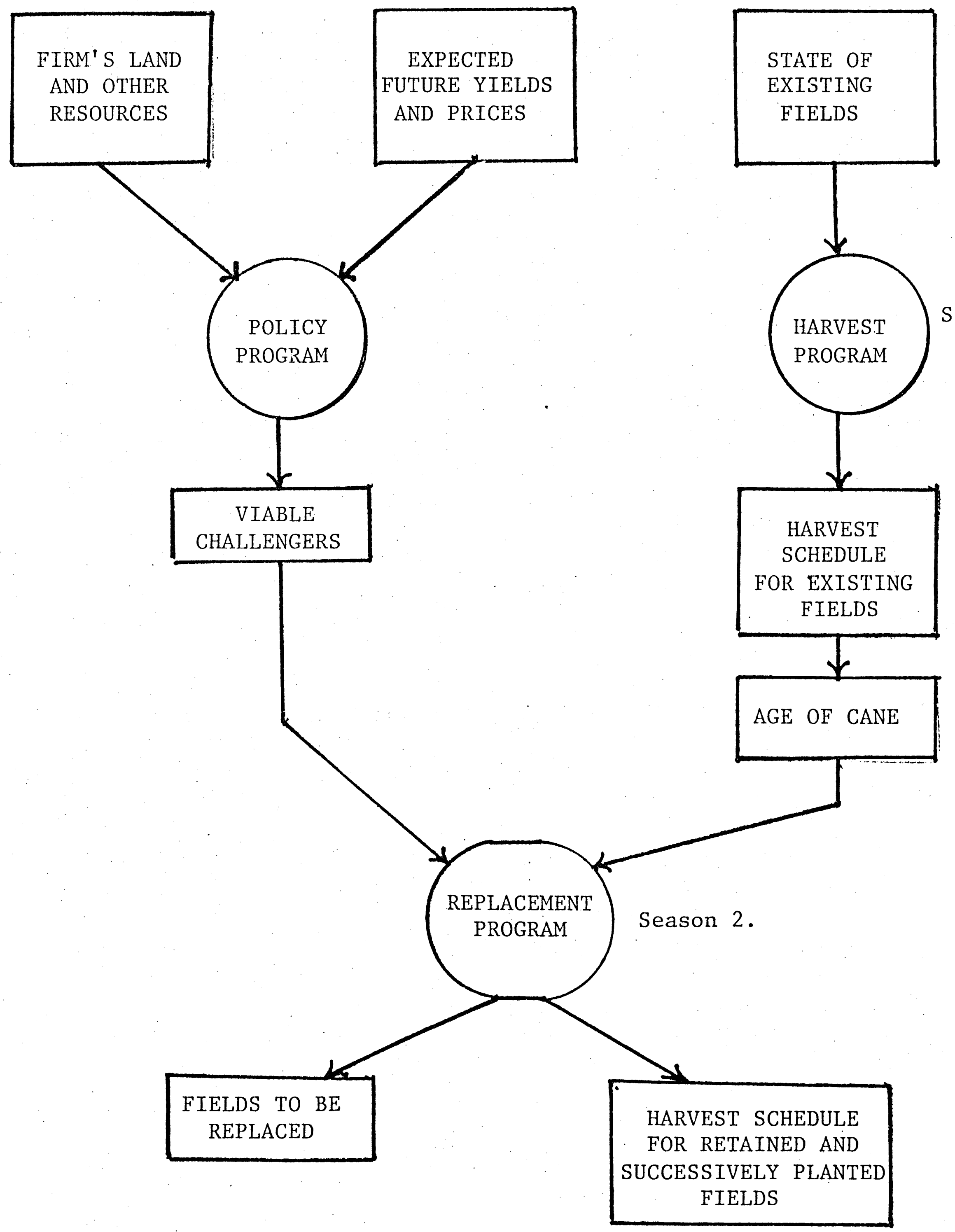

Figure 1. Diagram of the three-step replacement procedure.

resources, which varieties would be grown on each type of land, how many years would each be grown and during which period would each 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 may 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 also 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. While the harvest program is of considerable value to the cane grower in its own right, its principal purpose in the current 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 in order to maximize revenue. In the case of fields to be replaced, the replacement identifies the replacing challenger. For those fields not replaced or those successively planted, the program generates an optimum harvest schedule in Season 2. The grower, however, will update this schedule as new weather information is received during the growing season.

Concluding Comments

Space does not allow a mathematical description of the three optimization models. As the decision variables relate to fields, they are intrinsically integer. Thus, all three models are integer programming problems. The harvest and replacement programs, however, possess the structure of the classical transportation problem and thus can be efficiently solved through a variety of algorithms (Wagner, 1969, p.166). The policy program does not possess this special structure and its solution as an integer programming problem is not a simple matter. Feasible integer solutions to the policy program have been obtained by Crane (1979) for a relatively large problem (2442 integer activities), though optimality could not be proven.

A framework has been outlined to enable Florida sugarcane growers to analytically address the stubble replacement problem. The paper has pointed out the multitude of alternatives facing the grower which begs for a systematic approach to choose among those alternatives. If the data needs of the model proposed here can be met, the model provides that systematic approach.

Footnotes

1/ A succinct review of the literature in this area may be found in Rapp (1974, pp.I-1 to I-7). Additional work in this field of special interest to agriculturalists may be found in Faris (1960), Burt (1963, 1965), Chisholm (1966), Ward and Faris (1960), Perrin (1972, 1974), and Nelson and Purcell (1972).

2/ For a derivation of the capital recovery factor see Grant et al. (1976, p.35). Note: Grant's "P" is equivalent to the term in brackets in (15).

3/ Forecasts of yields and prices are not addressed in this paper. For an explicit treatment of sugarcane yield forecasting see Crane (1979).

References

Alvarez, Jose, Gerald Kidder, and George H. Snyder. 1979. "The Economic Potential for Growing Rice and Sugarcane in Rotation in the Everglades", Proc. Soil and Crop Sc. Soc. of Fla. 38(in press).

Barnes, A.C. 1974. The Sugar Cane. New York: John Wiley and Sons.

Burt, Oscar R. 1963. "Economic Replacement", SIAM Rev. 5(July),pp.203-208.

______________. 1965. "Optimal Replacement Under Risk", J. Farm Econ. 47(May),pp.324-346.

Chisholm, Anthony H. 1966. "Criteria for Determining the Optimum Replacement Pattern", J. Farm Econ. 48(Feb.),pp.107-112.

Crane, Donald R., Jr. 1979. "The Sugarcane Stubble Replacement Decision for South Florida". Gainesville: M.S. Thesis, University of Florida.

Faris, J. Edwin. 1960. "Analytical Techniques Used in Determining the Optimum Replacement Pattern", J. Farm Econ. 42(Nov.),pp.755-766.

Grant, E.L., W.G. Ireson, and R.S. Leavenworth. 1976. Principles of Engineering Economy. New York: The Ronald Press.

Hotelling, H. 1925. "A General Mathematical Theory of Depreciation", J. Am. Stat. Assc.

Kidder, G. and P.M. Lyrene. 1976. "A Traveler's Guide to Florida Sugarcane", Agronomy Facts, No. 59. Gainesville: University of Florida.

le Grand, F. 1972. Production of Sugarcane, Agronomy Monograph No. 1. Gainesville: University of Florida.

Mao, James C.T. 1969. Quantitative Analysis of Financial Deicsions. New York: Macmillan Publishing Company, Inc.

Nelson, K.E. and W.D. Purcell. 1972. "A Quantitative Approach to the Feedlot Replacement Decision", So. J. Agri. Econ. 2(July),pp.143-149.

Perrin, R.K. 1972. "Asset Replacement Principles", Am. J. Agri. Econ. 54(Feb.),pp.60-67.

Perrin, R.K. and E.A. Proctor. 1974. The Economics of Replacing Apple Trees--A Guide for Producer Decision Making. Raleigh: North Carolina State University, Economics Info. Report No. 36.

Preinreich, Gabriel A.D. 1940. "The Economic Life of Industrial Equipment", Econometrica 8(Jan.),pp.12-44.

Rapp, Birger. 1974. Models for Optimal Investment and Maintenance Decisions. New York: John Wiley and Sons.

Terborgh, George. 1949. Dynamics Equipment Policy. New York: McGraw-Hill Book Company, Inc.

Wagner, Harvey M. 1975. Principles of Operations Research. Englewood Cliffs: Prentice-Hall, Inc.

Ward, Lionel E. and J. Edwin Faris. 1968. A Stochastic Approach to Replacement Policies of Plum Trees. California: University of California Giannini Foundation Monograph No. 22.

Zepp, Glenn. 1976. "The Florida Sugar Industry: Its Past, Present and Future Prospects", USDA, Sugar and Sweetener Rep. 1(Sept),pp.45-50.