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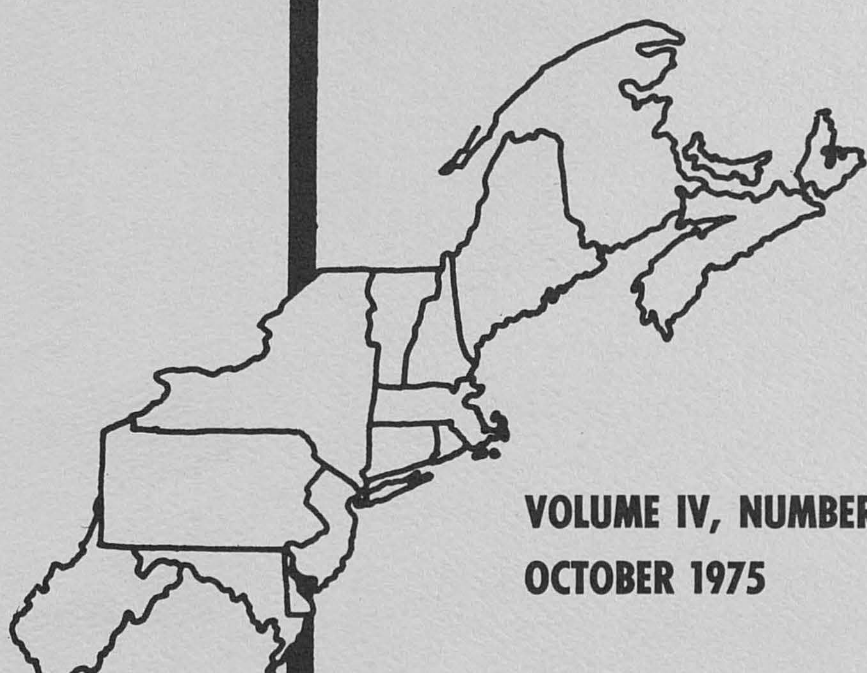

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VARIETAL MIX DECISION FRAMEWORK FOR MASSACHUSETTS APPLE GROWERS*

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Introduction

Apple production in Massachusetts has remained relatively stable 1/ for the past sixty years at about 2.7 million bushels annually [1], while output of most other agricultural enterprises in the state has declined. For a variety of reasons, Massachusetts apple growers have been better able to compete with other producing regions. Among the technological adjustments which have occurred, has been an expanded use of semi-dwarf rootstock resulting in a higher density of trees planted per acre. Changes also continue to be made in varieties of apples planted, reflecting both changing consumer tastes and improved varietal selections.

While many adjustments have taken place in the Massachusetts apple industry in recent years, there has been very little analysis of economic aspects of apple production and marketing. 2/ Since apple plantings

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1/ It should be noted that the number of orchards has decreased over this period. Average orchard size has expanded sufficiently, however, to leave aggregate output stable.

2/ Indeed, to the authors' knowledge, the only other application of operations research methods to problems such as ours is [4]. This study uses multi-period linear programming to develop strategies for replacing standard (very low density) apple trees with dwarfs (very high density). His work considers "when" to replace, while this study concerns "with what" to replace.

require from ten to fifteen years to achieve economic yields, it seems important that a grower have at his disposal as much technological and economic information as possible to guide him in making changes in the organization of his apple enterprise.

At present, the McIntosh and Delicious varieties account for slightly over seventy percent of all apple trees in Massachusetts [8]. Harvest season for McIntosh begins about mid-September and for Delicious begins from early to mid-October. The apple harvest season is consequently relatively short on many farms in the state. A short harvest season presents a number of problems to the growers especially the difficulty of hiring, training and managing a large number of pickers for the peak harvest period.

Most apple growers hire a basic core of regular labor on a full time basis for such operations as grading and packing, pruning, planting, and other production activities. From early August after spraying is completed for the season, both the operator and regular hired labor are available for harvesting operations. During peak harvest periods the operator and regular hired labor are required for non-picking activities such as training, supervising, hauling, and storing the crop. However, earlier and later in the harvesting season hired picking labor might not be required if acreage of early and late varieties is quite small and harvesting can be easily completed with available labor.

There are several recommended varieties which could be harvested from early August to mid-September before the McIntosh season starts and several varieties which are harvested after McIntosh continuing to late October. Thus, it is possible that, in terms of net returns and considering the use of available labor resources, it would be advantageous to have a better balance of early, mid season, and late season varieties. In addition to the obvious economic factors, there might also be less difficulty in recruiting and retaining picking labor if the season is lengthened. Also, from a managerial point of view, growers would be better able to supervise a smaller picking crew for a longer period than with a larger number of pickers for a short period of time.

The primary objective of this paper, then, is to develop a framework for choosing an "optimum mix" of apple varieties for planting over time. The framework is demonstrated for a model farm operating under production and marketing conditions similar to those which might be experienced in Massachusetts. This framework treats multiple farm goals in lexicographic fashion[3/] -- i.e., in this case the framework seeks to make varietal planting decisions over time so as to maximize the present value of net returns from the operation, with alternative goals such as

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3/ Examples of early use of this lexicographic approach can be found in [3] and [7].

minimum acceptable family living expenses and maximum acceptable risk treated as constraints. Further constraints reflect the limiting resources on the model farm. These include: available farm labor during the harvest season, present storage capacity, market limitations on early varieties, and capital available for reinvesting after family living expenses and fixed and variable costs are deducted. The framework utilizes a dynamic linear programming procedure for solution.

The General Framework

A framework for making investment choices (i.e., plantings of various varieties of apples in each decision period) is provided below. The primary objective is to maximize the present value of a stream of net income subject to a set of specified secondary objectives. The choices of variety and timing of plantings are subject to a number of additional constraints including regular labor during the harvest season, storage capacity, market limitations of certain varieties, total acres of orchard, and capital availability. The model takes the form of a dynamic linear programming framework, whose components (activities, objective function, and constraints) are set out seriatim.

Activities

The primary decision or control variables are assumed to be the number of acres of a particular variety i to plant in period t. Additionally, each variety may be divided into two partitions (j), where j = 1 denotes that all harvesting operations are carried out by full time labor (operator and regularly hired) and j = 2 denotes that such acres would be harvested using seasonally hired labor for picking. Finally, activities are defined which permit the borrowing of capital in any decision period and repayed over succeeding time periods.

The control variables are then:

x_{ijt} denotes the number of acres of variety i to be harvested under plan j in period t ($i = 1, \ldots, I$; $j = 1, 2$; $t = 1, \ldots, T$).

$x_{I+1,t}$ denotes the borrowing of one unit of capital in period t ($t = 1, \ldots, T$).

Objective Function

The primary objective is to select and plant varieties over time so as to maximize the present value of net returns. This is expressed:

(1) Maximize $Z = \sum_{ijt} c_{ijt}\, x_{ijt}$,

where:

Z is the present value of the expected stream of net returns resulting from the x_{ijt} planting decisions,

c_{ijt} denotes the present value of the stream of net income[4/] per acre expected from planting variety i in period t to be harvested by method j, and to be removed in period $t + \Delta$, where Δ is the useful life of variety i, and

x_{ijt} is as defined above.

Constraints

Since a limited amount of regular labor is generally available during the critical harvest seasons, a labor constraint is imposed for each seasonal harvest interval. Each variety has a peak or critical interval within which harvest labor needs are high and these labor needs are specific to its stage of development (age) since yield (and therefore harvest labor requirements) varies with age of the tree. For a particular seasonal harvest period (e.g., September 1-15), then, there are as many constraints as planning periods. These can be expressed:

$$(2) \quad \sum_{i,j,p} \sum_{t=1}^{t'} a_{ijpt*} x_{ijt} \leq b_{pt'}; \; t' = 1, \ldots, \Delta; \; p = 1, \ldots, P$$

and

$$\sum_{i,j,p} \sum_{t=t'-\Delta+1}^{t'} a_{ijpt*} x_{ijt} \leq b_{pt'}; \; t' = \Delta + 1, \ldots, T; \quad p = 1, \ldots, P$$

where:

a_{ijpt*} denotes regular harvest labor requirements (in period t') per acre for variety i using picking method j in harvest season p which was planted in period t, and

$b_{pt'}$ denotes the available regular labor during season p in period t'.

The harvest labor requirements a_{ijpt*} are, of course, zero for the period $(t' - t)$ before bearing age, then increase with $(t' - t)$ up to a maximum and declining slightly just before removal at $t + \Delta$.

4/ $c_{I+1,t}$ is, of course, the relevant interest rate.

Apples of mid and late season varieties can be and are generally stored. Since most operations have a fixed amount of storage space available, additional constraints are suggested:

$$(3)\quad \sum_{i} \sum_{t=1}^{t'} d_{it*}\, x_{ijt} \leq f;\ t' = 1, \ldots, \Delta$$

and

$$\sum_{i} \sum_{t=t'-\Delta+1}^{t'} d_{it*}\, x_{ijt} \leq f;\ t' = \Delta + 1, \ldots, T$$

where:

d_{it*} in the t' constraint denotes the yield per acre in t' of variety i planted in period t, and

f denotes the storage space available.

Obviously, available acreage restricts amounts which can be planted. This limitation is incorporated as:

$$(4)\quad \sum_{i,j} \sum_{t=1}^{t'} x_{ijt} \leq h;\ t' = 1, \ldots, \Delta$$

and

$$\sum_{i,j} \sum_{t=t'-\Delta+1}^{t'} g_{t*}\, x_{ijt} \leq h;\ t' = \Delta + 1, \ldots, T,$$

where:

$$g_{t*} = \begin{cases} 1, & \text{if } t' - t \leq \Delta, \text{ and} \\ 0, & \text{if } t' - t > \Delta \end{cases}$$

The marketing of early varieties is a special problem. The marketing season is short and the varieties are virtually unstorable -- in short, it is a very risky venture to maintain more than a few acres of these varieties. The decisions can be further constrained to reflect this situation, then, by:

$$(5)\quad \sum_{i,j} \sum_{t=1}^{t'} m_{ijt*}\, x_{ijt} \leq n_{it'};\ t' = 1, \ldots, \Delta;\ i = 1, \ldots, I_1$$

and

$$\sum_{i,j} \sum_{t=t'-\Delta+1}^{t'} m_{ijt*} x_{ijt} \leq n_{it'};\ t' = \Delta + 1, \ldots, T;$$
$$i = 1, \ldots, I_1$$

where:

m_{ijt} is marketable yield per acre for variety i in t' if planted in t under harvesting method j,

$n_{it'}$ is the total amount of variety i that can be marketed in t', and

I_1 is the number of early varieties subject to such market limitations.

Capital is another limiting resource on most apple farms. Incorporation of these constraints may take the form:

$$(6) \quad \sum_{i,j} \sum_{t=1}^{t'} r_{ijt*} x_{ijt} \leq S_{t'};\ t' = 1, \ldots, \Delta$$

and

$$\sum_{i,j} \sum_{t=t'-\Delta+1}^{t'} r_{ijt*} x_{ijt} \leq S_{t'};\ t' = \Delta + 1, \ldots, T$$

where:

r_{ijt*} denote cumulative expected net returns in t' per acre from variety i planted in t, and

$S_{t'}$ is the amount of capital available in t' and $S_{t'} = S_{t'-1}$ less family living expenses and fixed costs in t' - 1, and

$r_{I+1,t*}$ is a negative amount representing repayment of principle and interest in each period from t to t + Δ.

That is, capital is carried forward by slack variables for each period t', where net returns (costs for early periods of a planting) are aggregated for each relevant period t' over the interval t to Δ.

Finally, since credit is not unlimited, planting decisions in each period are constrained by:

$$(7) \quad x_{I+1,t} \leq Y_{t'};\ t' = 1, \ldots, T$$

where:

$Y_{t'}$ denotes the amount of capital that can be borrowed in each period t'.

Application

The decision framework provided above was applied to a model farm representing a rather typical apple orchard situation in Massachusetts. The values of the objective function coefficients, input requirements, and restraint levels were derived from in-depth conversations with local growers, from secondary sources, and by detailed budgeting procedures.5/

The model farm consists of eighty acres of apples of various age categories and varieties, as shown in Table 1. Planning periods were divided into five year intervals with replacement assumed at the end of five periods ($\Delta = 5$). The planting decision horizon (T) was arbitrarily set at five periods as well. Thus, trees planted at T are in production until $T + \Delta$, of fifty years into the future. This permits a set of decisions which explicitly recognizes the stream of future resource requirements occasioned by these decisions. Of course, in a realistic decision context, as new information (improved varieties, changing economic conditions, etc.) unfolds, the parameters of the model would be revised and updated so that decisions are made at each point in light of the most current information.

Some sample results of the application are provided in Table 2. For time period one, all varieties were planted except McIntosh. Initial plantings used all available regular harvest labor during the McIntosh harvest season in time periods one and two. McIntosh trees were, however, planted in subsequent time periods as harvest labor became available from the gradual removal of original plantings of this variety. Three early varieties (July Red, Puritan, and Paula Red) were planted to be harvested using regular labor only. These varieties were restricted by the estimated markets available to the model farm for early apples and only small acreages were planted.

Ethepon treated McIntosh, although similarly constrained by available markets, would require some hired pickers since original plantings were using some of the available regular labor. Since this is just prior to the regular McIntosh season, the hired pickers would thereby be trained for the peak harvest season.

5/ See [5] for the budgets used and a more detailed description of the production situation and data used.

Table 1

Acres of Existing Orchard on Model Farm by Variety and Age Category

Age of Trees	July Red	Puritan	Paula Red	McIntosh (Ethepon)	McIntosh	Macoun	Cortland	Red Delicious	Ida Red
1- 5 years	--	--	1.0	--	14.0	--	1.0	--	--
6-10 years	--	--	--	2.0	12.0	--	--	2.0	--
11-15 years	--	2.0	--	--	8.0	--	5.0	--	1.0
16-20 years	--	--	--	--	11.0	1.0	--	4.0	--
21-25 years	--	--	--	--	13.0	1.0	2.0	--	--
Total	--	2.0	1.0	2.0	58.0	2.0	8.0	6.0	1.0

Table 2

Acres of Apples Planted by Variety and Time Period and Harvested With Regular or Seasonal Labor

Variety	Time Period One		Time Period Two		Time Period Three		Time Period Four		Time Period Five	
	Regular Labor	Seasonal Labor	Regular Labor	Seasonal Labor	Regular Labor	Seasonal Labor	Regular Labor	Seasonal Labor	Regular Labor	Seasonal Labor
July Red	2.74	--	--	--	--	--	0.70	--	2.04	--
Puritan	2.64	--	0.23	--	--	--	0.63	--	2.22	--
Paula Red	1.25	--	1.78	--	--	--	--	--	2.89	--
McIntosh (Ethepon)	0.69	--	1.20	0.95	--	0.26	--	--	1.59	1.24
McIntosh	--	--	--	7.00	--	11.43	--	--	--	10.24
Macoun	1.80	--	--	--	--	--	--	1.80	1.38	--
Cortland	--	1.83	--	3.67	--	--	--	1.74	--	4.13
Red Delicious	0.63	3.13	--	1.17	--	--	--	3.06	1.02	0.34
Ida Red	1.29	--	--	--	--	--	0.30	--	0.99	--
Total	11.04	4.96	3.21	12.79	--	11.69	1.63	6.60	12.13	15.95

Shadow Prices

The selection of varieties is conditioned by the availability of resources which in turn depend on the amount of initial plantings existing in each time period. Not all resources are available for new plantings until the fifth time period, and plantings in that period are themselves affected by the trees planted in the first four periods of the planning horizon.

Shadow prices are shown in Table 3 for each resource in each time period. Resource availabilities for harvest labor and markets for early varieties were considered as far as the seventh time period to properly constrain plantings in the fifth time period. Consequently, shadow prices cover seven time periods; that is, two periods beyond the planning horizon.

Each variety shown in the optimum solution has completely used up one of the resources in one of the time periods. The shadow prices indicate the amount by which the value of the objective function (121,254 dollars) would increase if an extra unit of the resource could be acquired. A variety planted in a specific time period uses resources for five time periods. Consequently, the shadow prices refer to a resource in a particular time period but not necessarily to the time period in which a variety is planted. For example, the shadow price for regular harvest labor for Ida Red in the fourth time period is $6.53, and this is the resource which restricted the planting of this variety to 1.29 acres in the first time period.

In addition to examining shadow prices, sensitivity to levels of restrictions and assumed parameters was analyzed by varying these assumptions within reasonable levels. In all, fourteen different variations were examined, including changes in capital availability, marketing constraints for early varieties, and for several variations no initial orchard was assumed so that the orchardist had maximum freedom to plan the enterprise in the early periods. In general, the early varieties were planted to the maximum limits of available markets, indicating the relative profitability of early apples. McIntosh and Cortland were planted to the maximum acreage permitted by the availability of regular harvest labor and further used seasonally hired pickers. Macoun, Red Delicious and Ida Red were generally planted in small enough acreages so as to be harvested using only regular labor. Since these varieties could have been planted in sufficient acreage to require hired pickers throughout harvesting, it is apparent that they could not compete with the other varieties for available acres of orchard land.

The models further indicated that net income, from initial and new plantings, was sufficient to carry out the replanting program over the planning horizon without using borrowed funds. If market prices for varieties had been slightly lower than those assumed in the budgets, then borrowed capital would have been required (or at least living expenses reduced to allow the replanting program to be carried out).

Table 3

Shadow Prices (Dollars) of Limiting Resources for Seven Time Periods

Limiting Resource	Time Period One	Time Period Two	Time Period Three	Time Period Four	Time Period Five	Time Period Six	Time Period Seven
Acres	167.33	221.75	--	--	331.00	--	--
Capital	--	--	--	--	--	--	--
Borrow Capital	--	--	--	--	--	--	--
Storage	--	--	--	--	--	--	--
Labor							
July Red	--	--	--	--	--	--	--
Puritan	--	--	--	--	--	--	--
Paula Red	--	--	--	--	--	--	--
McIntosh (Ethepon)	--	--	--	7.33	--	8.01	5.34
McIntosh	--	5.44	73.34	--	--	37.45	18.51
Macoun	--	--	--	3.38	16.67	--	9.40
Cortland	--	59.65	3.54	42.83	--	15.69	22.43
Red Delicious	--	--	--	--	16.67	--	8.40
Ida Red	--	--	--	6.53	7.38	--	6.10
Market							
July Red	--	--	--	5.69	2.34	--	3.54
Puritan	--	3.91	--	5.25	2.82	--	4.26
Paula Red	--	--	3.66	--	4.97	--	3.54
McIntosh (Ethepon)	--	--	6.90	--	--	1.65	1.42

Conclusions

The purpose of this paper has been to develop a decision framework which can be useful to the apple grower in making planting choices regarding varietal mix. These choices are currently made on a rather informal and frequently erroneous basis. That is, the inefficient use of the labor resource, which generally results from too heavy concentration on the variety or varieties with the highest expected returns per acre, often overshadows (in costs) the incremental net returns of these "best" varieties from an overall farm viewpoint. The usefulness of the framework was demonstrated for a typical farm situation in Massachusetts, by means of a dynamic linear programming solution procedure with most of the coefficients derived by detailed budgeting analysis.

One advantage of the framework is that it formalizes the decision process and provides an efficient solution procedure. Another is that the framework is simple, inexpensive to use, and can be used for a wide variety of farm situations simply by altering constraint levels, input coefficients and expected net returns.

There are limitations to the framework of course. First, the general limitations of linear programming procedures are well-known.[6/] Other procedures (e.g., non-linear and integer programming) are available to cope with most of these limitations, but in this case the limitations appear not to be severe and the complexity of the alternatives in most cases rules them out as practical decision tools for growers.

Other limitations refer to the choice of constraints for this application. This choice reflected what several participating growers felt were the most important limiting factors. Others may be important for other situations, and these can generally be added to the framework above. For example, no constraints were entered to ensure that each variety would be planted along with other varieties that are good pollinators. For individual situations, these combinations could be discussed with tree fruit specialists and appropriate constraints specified. Likewise, the replacement timing decision was treated exogenously here. With some sacrifice in simplicity, these decisions could be made endogenous. It may also be useful to require that a variety be planted in blocks of some minimum size. With further loss of simplicity, this can also be accomplished (by integer programming procedures). However, it is contended here that the general framework presented above, with any additional constraints specific to the individual preferences and situation of the grower decision-maker, can provide a useful tool for choosing varieties of apples to plant over time.

6/ See, for example, [2, p. 21] and [6, p. 42].

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