Modeling to Generate Alternatives in a Multiperiod Context: Apple Growers and Alar

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Introduction

Farm management decision making would be enhanced if solutions to farm problems were offered as a set of feasible alternatives, rather than as a single "best" solution for achieving favorable results. A farm manager could evaluate an array of alternatives against the farm's unique characteristics, which frequently are difficult to quantify and model, and select the most efficient action for the farm. Often, when agricultural economists use optimization, a single optimal solution is presented, with the corresponding best method for implementation. If the optimal solution is not appealing, the farmer does not move toward more efficient practices because alternatives are not offered. It is possible, however, to eliminate black-and-white solutions and increase the choices offered to operators. Two techniques for this are the examination of nearly optimal solutions (NOS) and modeling to generate alternatives (MGA).

Brill et al., Willis and Petraglia, and Burton et al. used single-period models to demonstrate the appropriateness of MGA and the added information obtainable by generating NOS. To date, no studies have incorporated MGA into a multiperiod model. This research broadens the applicability of MGA to multiperiod, long-range decision contexts.

When farmers adopt new chemicals to improve farm efficiency the adjustment of farm practices is usually smooth. However, when an important chemical is withdrawn for health or environmental reasons, the adjustment can be rough and disruptive. Farmers must respond as well as possible to the reduction or elimination of a chemical that is integral to production.

This problem arose for apple growers in 1986 when they were threatened with withdrawal of the chemical daminozide, commercially known as Alar. Daminozide had been embedded in orchard management practices for two decades, particularly for McIntosh growers, with no substitute for the growth regulator for commercial use. This paper offers suggestions for apple orchard renewal as a long-term solution to the problems resulting from reductions in use of Alar.

Research in long-range orchard renewal has focused on altering model parameters and assumptions. One problem is that all farm factors cannot be quantified. Hanlon et al. developed a framework for long-range apple varietal decisions and generated at least ten linear programming (LP) models in an attempt to represent different farm management practices. Kimball and Autio modeled five farm scenarios by altering resource constraints, using LP to generate optimal schedules for replacing standard McIntosh trees with more economically viable dwarf and semi-dwarf rootstocks. Although many different farm situations were identified, both studies offered only one solution to decision makers for each model.

This paper enriches the economic analysis of orchard rejuvenation by adhering to the parameters and assumptions of one orchard model and examining NOS. The paper also attempts to demonstrate the richness of information obtained by using MGA for multiperiod models, information masked in standard LP procedures.

Methodology

This study incorporates the Hop, Skip, and Jump (HSJ) technique (Brill et al.) for modeling to generate alternatives into a multiperiod linear framework. The method is a two-step procedure. Initially, the optimal solution is generated using the standard expressions for a multiperiod model:

(1) $$\text{Maximize } Z = c'x,$$
(2) $$\text{subject to: } Ax \leq b,$$
(3) $$x \geq 0,$$

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where Z is the value of the objective function over time, c′ is the profit vector per activity in each time period, x is the activity vector, A is the resource coefficient matrix, and b is the resource constraint vector.

The HSJ technique uses the optimal solution as a base from which to generate nearly optimal solutions. The intent is to provide new solutions with similar objective function values to the optimal solution yet differ substantially in the activities. In these NOS, values of the activities differ from those selected in the optimal solution, but the value of the objective function is within a specified percentage of the optimal value.

To force the model to select activities that differ as much as possible from the optimal solution, a new objective function is formulated. It is minimized with a new c′ vector (c*) in which variables are assigned a value of 1 if basic in the optimal solution and 0 if not. The objective function is

$$(4) \qquad \text{Minimize } Z^* = c^*x.$$

To ensure that the objective function of a NOS is within a specified tolerance level (P_k) of the optimal solution value (Z^o), the optimal objective function augments the constraint matrix Ax, and Z^o becomes a member of the resource constraint vector b. This constraint is expressed as:

$$(5) \qquad c'x \geqslant Z(1 - P_k).$$

An initial LP solution is generated by maximizing (1), subject to (2) and (3). For each subsequent run, the objective function (4) is altered so that all previous basic variables are valued at 1 and nonbasic variables at 0, and (5) is added to (2) and (3). Nearly optimal solutions within the tolerance level specified can be generated until the basic variables do not change from the previous solution. Solutions become less distinct from the optimal solution with successive generations.

Additional NOS can be generated by changing P_k and repeating the procedure. The wider the tolerance range, the more distinct the alternative solutions from the original optimal solution.

Application

Since 1966, daminozide has been used to extend the apple harvest season by controlling fruit drop and delaying fruit ripening, enabling growers to manage harvest labor and cooling capacity more efficiently. In 1985, Alar was sprayed on 80% of bearing McIntosh acreage in Massachusetts (Autio). Without daminozide, the number of harvest days decreases, thus increasing the quantity of fruit that must be harvested each day. To accommodate this harvest peak, picking labor and cooling capacity must be increased, raising production costs. Alternative methods of extending the harvest season would help alleviate this critical problem.

The long-term solution of replanting orchard acreages with a mixture of strains and rootstocks that retain commercially profitable varieties while expanding the harvest season was examined by Kimball and Autio. In that study a multiperiod linear programming model developed for long-range apple varietal decisions (Willis et al.) was adapted to current orchard management practices for Massachusetts farms. Five ten-year replanting schedules were generated; each maximized the present value of net returns to management over a 20 year time horizon and differed by the amount of harvest labor and cooling capacity available to the farm.

Only a single solution was generated for each case. Extension specialists did not offer a set of alternative replanting plans from which a farm manager could make a final decision based upon a farm's unique characteristics.

Several questions are raised by a unique, optimal solution. How different would a second and third best solution be from the optimal? How much can the replanting schedule change and be within a given percentage of the optimal returns to management? Would alternative planting schedules emphasize changes in the timing of planting or changes in the strain-rootstock combinations selected? What percentage of activities in the optimal solution would be duplicated in alternative solutions?

Generating NOS using the HSJ technique in this multiperiod setting suggests answers. To explain the adaptation of HSJ to this multiperiod model, the methodology of the original model is presented first.

The objective of the original model is to determine the best schedule for replanting seedling McIntosh acreages with other strains to maximize net returns to management. Given the commercial importance of McIntosh, the model retains the variety and replants with a mix of McIntosh strains on dwarf and semi-dwarf rootstocks that enable better management of labor and cooling facilities at harvest.

The strains examined are: 1) Marshall McIntosh on M.7A rootstock to give a smaller tree that produces fruit with better color and an earlier harvest; 2) Rogers McIntosh on M.7A to give a smaller tree with fruit harvested at the normal time; 3) Marshall McIntosh on M.26 to give an even smaller tree capable of producing fruit for a rapid, early harvest; and 4) Marshall McIntosh on experimental

OAR 1, which may potentially produce highly colored fruit ripening about 10 days later than normal.

The standard McIntosh trees being replaced are fully mature and provide revenue while the replanted strains are growing to bearing age. Net returns to management cover overhead costs, management's labor, and profit.

Revenues are dependent upon yield, which varies according to the tree's age, the strain-rootstock combination, and the price. Price is held constant for all years but varies with fruit grade. For all trees, yield is distributed 75% as extra fancy, 15% as utility, and 10% as processing, with prices per bushel of \$10.00, \$5.00, and \$2.30, respectively. Differences exist between the newly planted trees and the standard trees as to the distribution of fruit into grades, but to simplify the model the proportions are held constant and the differences are accounted for with yield variation.

Total costs for each strain-rootstock combination is the sum of the costs of site preparation, planting, nonbearing growing years 1 through 3, bearing years 4 through 20, harvesting, cooling, and storage. All costs are figured on a per acre basis using current prices.

Due to the 20 year life of the trees, returns to management accumulate beyond the 10 year planting schedule and are calculated per acre for all strain-rootstock combinations. An acre planted in year 1 incurs costs of site preparation, planting, and nonbearing maintenance through the first 3 growing years with no revenue received. In year 4, when trees begin to bear fruit, revenues are positive and increase through maturity.

The total returns to management for all planting years were summed for each strain-rootstock combination. Then the present value of these totals was calculated using a 7% interest rate. Finally, the present value for each planting year was summed. This value is the contribution of each acre to net returns to management for each strain-rootstock combination over the 20 year life of the replanted 50 acres.

The objective function of the original model, which maximizes the present value of net returns to management over the 20 year life of a replanted 50 acre McIntosh orchard, is

$$\text{Maximize } Z = \sum_{i=1}^{4} \sum_{t=1}^{10} c_{it} x_{it},$$

where:

Z = present value of a stream of net returns to management from all strain-rootstock combinations planted over the 10 year planning horizon. Returns are received for the 20 year life of the orchard.

c_{it} = present value of a stream of net returns to management per acre from strain-rootstock i planted in year t with a life of 20 years.

x_{it} = number of acres of strain-rootstock i planted in year t.

Four possible activities in each of ten time periods constitute a total of 40 activities.

The choices of McIntosh combinations are subject to constraints on cooling capacity, harvest labor availability, storage capacity, and annual replanting acreage. In HSJ the constraints are identical. Use of resources extends 20 years and within each year the labor and cooling constraints are multiperiod; the total number of constraints is 350.

The planning horizon for the 50 acre replanted orchard is 10 years. Five acres are replanted annually. Each year the model decides how many acres of each strain-rootstock combination to plant.

The acreage constraint is

$$\sum_{i=1}^{4} x_{it} = 5 \text{ acres} \quad \text{for } t = 1, \ldots, 10$$

Storage capacity is the total quantity of apples that can be placed in a long term storage facility, i.e., controlled atmosphere storage. This model assumes that all apples produced on the 50 acre block will be placed in long-term storage and sold wholesale later in the season. Storage space becomes available as 5 acres of standard trees are removed every year. Plantings do not require storage until they begin bearing fruit in year 4. The rate at which space becomes available exceeds the rate at which it is required by plantings so storage is not restrictive until most trees reach maturity. The annual per acre contribution of a strain-rootstock combination to storage is the yield per acre at a particular age.

The storage capacity is

$$\sum_{i=1}^{4} \sum_{t=1}^{10} Y_{itr}\, x_{it} \leq S_r$$
$$\text{for } r = 1, \ldots, 20$$

where:

Y_{itr} = yield, measured in bushels per acre, during year r of strain-rootstock i planted in year t.

S_r = number of bushels of storage capacity available in year r. In the initial year, S_r is storage capacity less the amount required for yield from the established trees. In subsequent periods, storage required for established trees diminishes, while space needed for yield from young trees begins increasing in year 4. Thus, S_r grows toward capacity throughout the planting years, reaching capacity at year 10 when all original trees have been removed.

The harvest season is divided into eight 3-day picking periods extending from September 4 to October 1. A percentage of the annual yield for each strain-rootstock combination is harvested during at least 4 of these picking periods. The harvest labor hours available for each period is determined by the number of pickers and the hours worked for every 3-day picking period. For the 50 acres, 189 labor hours are available per 3-day period. Each strain-rootstock combination utilizes harvest labor depending on the yield, the tree's age, the percentage of yield harvested during a particular picking period, and the picking rate. In year 20, when plantings are mature, harvest labor increases to 550 hours per 3-day period to enable the entire crop to be picked.

The harvest labor constraint is

$$\sum_{i=1}^{4} \sum_{t=1}^{10} h_{itrp}\, x_{it} \leq H_{rp} \qquad \text{for } r = 1, \ldots, 20 \;\; p = 1, \ldots, 8$$

where:

h_{itrp} = number of harvest labor hours required per acre during year r to pick strain-rootstock i planted in year t and harvested during picking period p.
H_{rp} = number of harvest labor hours available during year r in picking period p.

Field heat must be removed from the apples after harvest. Cooling capacity is the total quantity that can be cooled in each 3-day picking period. The cooling capacity required for each strain-rootstock combination depends upon the percentage of total yield harvested during a particular picking period. The capacity available for cooling fruit from replanted trees is the total capacity minus the amount required for fruit from the established trees. As acreage of established trees is removed, cooling capacity required for these trees decreases; capacity available for fruit from new plantings increases faster than their yield levels require.

The cooling capacity constraint is expressed as:

$$\sum_{i=1}^{4} \sum_{t=1}^{10} y_{itrp}\, x_{it} \leq C_{rp} \qquad \text{for } r = 1, \ldots, 20 \;\; p = 1, \ldots, 8$$

where:

y_{itrp} = number of bushels cooled per acre during year r of strain-rootstock i planted in year t and harvested during picking period p.
C_{rp} = number of bushels that can be cooled during year r in picking period p.

For HSJ, three tolerance ranges $(1 - P_k)$ are calculated with P_k equal to .20, .10, and .05. Within each range three solutions are generated with the objective of creating replanting schedules as varied from the optimal schedule as possible. This is accomplished by formulating an objective function that minimizes the number of acres from the optimal solution to be included in the alternative solutions. Hence, the HSJ objective function is expressed as:

$$\text{Minimize } Z^* = \sum_{i=1}^{4} \sum_{t=1}^{10} c^*_{it}\, x_{it}$$

where:

Z^* = number of acres of the optimal solution that appear in a NOS.
c^*_{it} = 1 if an activity is basic in previous solutions and 0 otherwise.

The constraints of the original multiperiod model are amended to include the tolerance range of the original objective function. This constraint is expressed as:

$$\sum_{i=1}^{4} \sum_{t=1}^{10} c_{it}\, x_{it} \geq Z^{o}(1 - P_k) \qquad P_k = .05, .10, \text{ or } .20$$

where Z^{o} is the value of the original optimal solution ($12,812,063).

Results

The discussion of results focuses on the questions raised earlier regarding the limitations of a unique optimal solution. Comments on the differences between the optimum and the alternatives are given and are followed by a discussion of the activities (x_{it}'s) selected in the NOS with respect to the strain-rootstock combinations selected and the timing of planting.

Strain-Rootstock Selection

Table 1 presents the optimal 10 year planting schedule for the 50 McIntosh acres as determined by the original model. For the entire replanted

Table 1. Planting Plan for the Optimal Solution (Acres)

Planting Year	Rogers M.7A	Marshall M.7A	Marshall M.26	Marshall OAR 1
1	0	0	5	0
2	0	0	2.2	2.8
3	0	0	0	5
4	0	0	3.9	1.1
5	0	0	5	0
6	0.1	0	4.9	0
7	0	0	5	0
8	0	0	5	0
9	0	0	5	0
10	0	0	0	5
Total	0.1	0	36.0	13.9

acreage, 72% is comprised of Marshall scion on M.26 rootstock, 27.8% of Marshall on OAR1 rootstock, less than 1% of Rogers on M.7A, and no Marshall on M.7A.

Table 2 displays the total acreage distribution for the optimal and NOS generated by HSJ at the three tolerance ranges. The sum of the values of each activity over all time periods in the replanting schedule is presented.

Z* is the value of the objective function of the HSJ solutions. It identifies the number of activities generated in a NOS that are identical to the optimal solution. Within the 5% tolerance range (P_k = .05), HSJ 1 is composed of 23 acres of the optimal solution; these acres are identical in the strain-rootstock combination selected and the timing of replanting to the optimal solution. Hence, 27 of the total 50 acres for HSJ 1 differ from the optimum. With additional generations within a tolerance level, Z* increases and the HSJ solutions become less distinct from the optimal solution.

The highest Z* value correlates with the NOS most similar to the optimal solution. Theoretically, this value should appear under the third HSJ solution of the lowest tolerance range. HSJ 3 in the 5% tolerance range generated the highest Z* value of 43.48; approximately 43 of the 50 replanted acres are identical in timing and strain-rootstock combinations to the optimal solution. The NOS with the smallest Z* value differs the most from the optimal solution. Theoretically, this value correlates with the first HSJ solution generated under the widest tolerance range. In fact, within the 20% tolerance range HSJ 1 did generate the smallest Z* value, 20.82 acres of the optimal solution. This solution is also attained in HSJ 1 of the 10% tolerance range.

The content of these NOS and the adjustment of the optimal solution is examined next. How they differ from the optimal solution, whether in the strain-rootstock selected or in the timing of planting, or both, is analyzed.

Within the 5% tolerance range, HSJ 1 is composed of 23 acres of the optimal solution; a grower could adjust the optimal replanting schedule by more than 50% and obtain 95% of the optimal net returns to management. Selection of Marshall/M.7A increases to 30% (14.9 acres) of the total acreage; none was chosen in the optimal solution. Marshall/M.26 is reduced by half, dropping from 36 acres in the optimal solution to 17.2 acres in this alternative. Marshall/OAR1 increases by 4 acres, and no Rogers/M.7A is selected in this solution.

Similar changes result in HSJ 2 under the 10% tolerance range. Marshall/M.7A increases from the optimum but only to 8.2 acres or 16.4% of the total acreage. Marshall/M.26 is cut in half to 19 acres in the alternative solution. Marshall/OAR1 plantings increase by 8.9 acres, and, again, no Rogers/M.7A is chosen.

In most of the HSJ alternatives Rogers/M.7A is not selected. This strain-rootstock has growing characteristics similar to the established McIntosh trees being rejuvenated. Replacing with Rogers/M.7A does not expand the harvest season, and, therefore, does not alleviate any pressures of a more condensed harvest season caused by the nonuse of Alar.

Marshall/M.26 was favored in the optimal solution. The model suggested planting 36 of the total 50 acres with Marshall/M.26. The early coloring strain and the more open tree in this combination gives the earliest and longest harvest season of the trees considered. Also, because of its precocity, Marshall/M.26 reaches full production earlier than other strain-rootstock combinations. Therefore, this combination has less competition for labor and cooling capacity, which are the primary factors leading to its selection in the optimal solution.

Within all the tolerance ranges of the NOS, se-

Table 2. Acreage Distribution Summed for All Time Periods

Strain-Rootstock Combinations	Optimal Solution	HSJ Solutions $P_k = .05$ 1	$P_k = .05$ 2	$P_k = .05$ 3	$P_k = .10$ 1	$P_k = .10$ 2	$P_k = .10$ 3	$P_k = .20$ 1	$P_k = .20$ 2	$P_k = .20$ 3
					(acres)					
Rogers/M.7A	0.1	0	0	1.4	0	0	1.0	0	0	0
Marshall/M.7A	0	14.9	5.0	6.1	11.3	8.2	8.3	11.3	5.0	12.3
Marshall/M.26	36.0	17.2	24.0	23.3	18.5	19.0	22.0	18.5	20.1	18
Marshall/OAR1	13.9	17.9	21.0	19.2	20.2	22.8	18.7	20.2	24.9	19.7
Z* (acres of optimal solution in NOS)	—	23.0	35.5	43.5	20.8	32.4	41.6	20.8	30.5	38.9

Table 3. Acres Selected Per Year for HSJ 1

Time Period (Yr):	1	2	3	4	5	6	7	8	9	10	Total
$P_k = .05$											
Rogers/M.7A	0	0	0	0	0	0	0	0	0	0	0
Marshall/M.7A	0	0	2.5	0	0	0	5	5	0.7	1.7	14.9
Marshall/M.26	2.3	5	0	5	0	4.9	0	0	0	0	17.2
Marshall/OAR1	2.7	0	2.5	0	5	0.1	0	0	4.3	3.3	17.9
TOTAL											50.0
$P_k = .10$ and $P_k = .20$											
Rogers/M.7A	0	0	0	0	0	0	0	0	0	0	0
Marshall/M.7A	0	0	5	0	0	0	5	0.2	0	1.1	11.3
Marshall/M.26	0	5	0	5	0	2.9	0	4.8	0	0.8	18.5
Marshall/OAR1	5	0	0	0	5	2.1	0	0	5	3.1	20.2
TOTAL											50.0

lection of Marshall/M.26 was cut approximately 50%. The HSJ alternative most different from the optimal (P_k = .20, HSJ 1) suggests planting 18.5 acres while the NOS most similar to the optimal solution (P_k = .05, HSJ 3) suggests planting 23.3 acres. The decrease in Marshall/M.26 was offset by increased plantings of Marshall/OAR1 and Marshall/M.7A in the NOS.

Marshall/M.7A does not appear in the optimal solution; however, it was selected significantly in all NOS. The percentage of total acreage composed of this strain-rootstock ranged from 10% (P_k = .20, HSJ 2) to 29.8% (P_k = .05, HSJ 1). Marshall/M.7A competes with Marshall/M.26 for resources during the same harvest periods. Marshall/M.7A has a somewhat shorter harvest season than Marshall/M.26, and a higher percentage of the crop is picked during the first week. Also, Marshall/M.7A reaches full production a year later than Marshall/M.26, so it has a slight revenue disadvantage. The timing of planting is critical to the inclusion of Marshall/M.7A in the NOS.

Acreages of Marshall/OAR1 increased from the optimal solution in all alternatives. Optimally, Marshall/OAR1 composed 27.8% of the replanted acres; under the NOS this strain-rootstock composed from 35.8% to 49.8%. Marshall/OAR1 is an experimental strain-rootstock combination presently being field tested; it should yield later in the season and extend harvest at least 3 days beyond other combinations. A disadvantage is that full production is not reached until approximately 3 years after Marshall/M.26. Hence, its contribution to returns is delayed. The inclusion of this strain illustrates how a strain-rootstock combination that ripens later than normal can be advantageous because of its ability to extend the harvest season and reduce competition for harvest labor and cooling.

Suppose an orchard manager's objective is to remain within 5% of optimal net returns to management. How can the strain-rootstock selection be varied? One method is to reduce the acres of Marshall/M.26 and replace them with additional acres of Marshall/OAR1 and Marshall/M.7A. But the same general recommendation could be made for the wider tolerance ranges as well. If only the growing characteristics differentiating these trees determined the proportion of each selected by the model, significant differences in the NOS among the tolerance ranges would have resulted. As shown, this did not occur. Another factor contributing to the model's selection process is the timing of replanting within the 10 year period. Now we turn to the multiperiod aspect of the model and compare HSJ solutions from this viewpoint.

Timing of Planting

This section shows that the MGA approach gives important timing information not revealed in the optimal solution. To reiterate, the acreage constraint requires replacement of five acres during each time period. The model determines the amount of each strain-rootstock to plant within the limits of the cooling, storage, harvest labor, and net returns to management constraints with the objective of minimizing the number of acres of the optimal solution comprising the NOS.

Table 3 enables comparison of the acreages selected during each time period for HSJ 1 among the three tolerance ranges. For example, in year 1, under tolerance ranges of both 10% and 20% 5 acres of Marshall/OAR1 are chosen; whereas, in the same year under the 5% tolerance range, 2.3 acres of Marshall/M.26 and 2.7 acres of Marshall/M.7A are chosen.

The first HSJ solutions are selected for comparison because, in all tolerance ranges, HSJ 1 generates the most different NOS. Identical first NOS resulted for tolerance ranges of 10% and 20%. Widening the tolerance range from a P_k of .10 to a P_k of .20 results in no solution change. However, widening the tolerance range from a P_k of .05 to a P_k of .10 generates a different NOS.

To remain within 5% of the optimal net returns, plantings of Marshall/M.26 are completed before year 7. In other tolerance ranges, selection of Marshall/M.26 is not completed until year 10. The 10% and 20% ranges generate 1.3 more acres of Marshall/M.26 than the 5% range, but 5.6 acres are selected after year 6 in the wider ranges. Although the total Marshall/M.26 acreage chosen is approximately the same (17.2 acres versus 18.5 acres) the timing of these activities varies significantly among the tolerance ranges.

The timing of strain-rootstock Marshall/M.7A is opposite that of Marshall/M.26. To obtain net returns to management within 5% of the optimum, more total acreage of Marshall/M.7A (14.9 acres) is selected than in the 10% and 20% tolerance ranges (11.3 acres). Yet in the 5% range, fewer acres appear prior to time period 7 than in the wider ranges (2.5 acres versus 5 acres in year 3). In the wider tolerance ranges 56% of the Marshall/M.7A acreage is selected in years 7 through 10, while in the narrower 5% tolerance range selection of this activity climbs to 83% in the same time periods.

A possible reason for a NOS to remain closer to optimum by selecting Marshall/M.7A in the later years and Marshall/M.26 in earlier time periods is that Marshall/M.7A reaches full production 1 year later than Marshall/M.26 so returns to management are delayed. By choosing Marshall/M.26 in earlier time periods, cash returns are received sooner.

For Marshall/OAR1, 2.3 fewer acres are chosen in the 5% range than in the 10% and 20% ranges. Once again, timing is more significant than the quantity difference. In this case, although the 5% range requires fewer acres, they are spread across 6 time periods; whereas, in the wider tolerance ranges the greater acreage is spread across only 5 time periods.

Within all tolerance ranges, no Rogers/M.7A was selected.

The NOS disclose the importance of timing when developing long range rejuvenation schedules. By not following timing specifications, net returns to management could be reduced to 80% or 90% of the optimum instead of reaching a 95% goal.

These findings call for a revision of Kimball and Autio's recommendations that were based only upon unique optimal solutions of the original model resulting from varying the values in the resource constraint vector. Referring to Table 1, Marshall/M.7A is not in the optimal replanting schedule. Based on the NOS, Marshall/M.7A could be included in a replanting schedule provided it follows the planting of a more precocious strain-rootstock, such as Marshall/M.26. The key to Marshall/M.7A's use is the timing in the 10 year rejuvenation horizon.

Clearly, MGA provides valuable information about timing for multiperiod problems that is unattainable when only generating optimal solutions.

Concluding Comments

As always when applying a LP model to actual farms, the assumptions and constraints do not fit all farm operations. This limitation, together with consideration of only the optimal solution, narrows the usefulness of such modeling to decision makers. In multiperiod models, an optimal solution results from the relationship of characteristics of each decision variable within one time period and the relation of these characteristics among time periods. An understanding of the interrelatedness of these two factors is masked within optimality. Using MGA for multiperiod models reveals the influence of timing on solutions and the significance of decision variable proportions.

In this long-range planning model for orchard renewal, changes in the proportion of decision variables selected over all time periods mark the difference between the optimal solution and all nearly optimal solutions. However, among the nearly optimal solutions, the timing of decision variable selection is the key difference and not the total proportions. Unveiling this subtlety through MGA suggests revision of extension recommendations for long-range orchard planning; original recommendations were based upon optimal solutions of the original model.

The generation of nearly optimal solutions exposes information and options previously hidden behind the unique LP solution. In a multiperiod model, particularly when long-range decisions affect several decades of profits, modeling to generate alternatives reveals information about the timing of decision variables and the proportions of decision variables. With MGA, long-range planners can be offered a diverse set of solutions that include the optimum and alternatives that fall within a specified range of the optimal solution. Decision makers may select from NOS and consider criteria not quantified in the model. With this information it may be possible to better evaluate specific farm needs.

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