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A DYNAMIC PROGRAMMING APPROACH TO APPLE ORCHARD REPLACEMENT

Robin A. Childs
Robert A. Milligan
Gerald B. White
Warren C. Stiles

Department of Agricultural Economics
Cornell University Agricultural Experiment Station
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853

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INTRODUCTION AND BACKGROUND

Fruit and nut growers contributed about six billion dollars to the United States agricultural economy in 1981, according to USDA estimates (USDA, 1982). Citrus fruits accounted for 32 percent of that total, grapes represented 20 percent, and apples comprised 15 percent of the total. New York State is the second largest producer of both apples (90 million dollars) and grapes (36 million dollars) in the United States. In 1980 there were 74,346 acres of apples in New York, according to the 1980 New York Orchard and Vineyard Survey. Apple production is concentrated in the Hudson Valley and along the shores of Lake Ontario in Western New York (Figure 1). In those regions, the agricultural economy is heavily dependent upon the apple industry.

One of the most difficult questions facing fruit growers is when to replace trees and vines. The reason for replacing trees and vines is declining profitability. Declining profitability can be the result of poor management, aging trees or vines, declining yields, rising costs, declining prices, insects or diseases, several consecutive years of bad weather, changing market conditions or some combination of these factors.

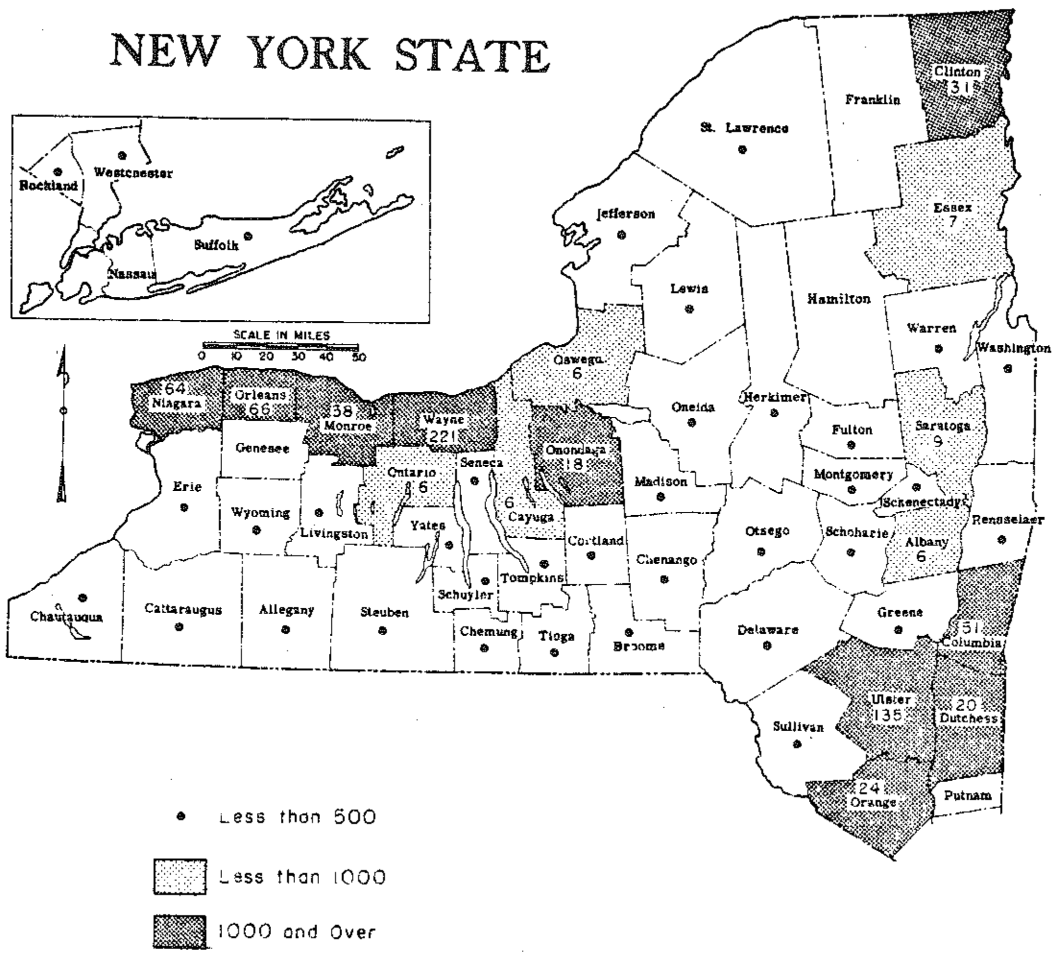
Whatever reason a grower may have for replacing an orchard or vineyard, the result is always a substantial investment of time and capital. The replacement of fruit crops is unique among crops in that the grower not only must make the initial outlay for the trees or vines, for land preparation, and for planting; but the trees or vines, once planted, must be nurtured and cared for for several years until they begin to produce fruit. In the case of standard (full size) apple trees, a new planting may require seven years until significant production begins. During those seven years, operating expenses of nearly $2,200 per acre, exclusive of interest charges, accumulate in addition to the initial establishment costs of $1,000-$2,000 per acre.

The problem of replacing apples is further complicated by changing technology. The apple industry is undergoing major transformations, and the choice among alternative planting systems and tree sizes makes the replacement of apple orchards a uniquely challenging problem. This project focuses on the replacement of apple trees in New York State, but the methodology is applicable to other tree and vine crops.

Background

Apples were introduced to New York State by the earliest settlers, who carried seedlings and seeds from their homes in Europe. Plantings were soon widespread throughout the state, as nearly every rural household possessed a small orchard for home consumption or a large orchard for commercial sales. As the settling process leveled off in the 19th century, the number of orchards in New York began to decline. This decline in orchard numbers was due in large part to the increasing urbanization of the population. Fewer home orchards were maintained, leading to increased demand for commercial production. Commercial producers, in turn, began to feel the pressures of competition and increased specialization. The result was that marginal orchard sites were abandoned. Climatic and soil limitations became critical under competitive conditions.

Figure 1. Distribution of the New York State Apple Industry in Acres



Source: Stanton, B.F., and W.A. Knoblauch. New York Agriculture Census Data, 1978. A.E. Extension 81-27, Cornell University, 1981.

The apple industry entered the 20th century with a continuing trend toward fewer and larger orchards. Innovations were limited mainly to cultural practices, disease and insect control, and breeding for perfection of varieties and disease resistance. The trees were still primarily full size trees grown on seedling rootstocks, although some experimentation with size control was imminent.

Dwarfed fruit trees, used for ornamental purposes as well as for their fruit, have existed for many centuries (Tukey). There was not much interest in their use for commercial fruit production, however, until the early nineteenth century. During the nineteenth century, research focused on vegetative propagation of fruit trees with the goals of size control and uniformity of tree size. As more development occurred, it became more difficult to classify rootstocks, and the necessity arose for standardization of rootstock material.

Hatton, continuing an effort initiated by Wellington in 1912, accomplished the task of classifying and naming 16 clonal rootstocks. Since Hatton worked in East Malling, England, the series of rootstocks that he identified was named the "East Malling", or "EM" series. Today there are more than Hatton's original 16 rootstocks in the "EM" (shortened further to "M") series, with M-9 being the most widely used dwarfing apple rootstock.

In the 1920's it was felt that the available standardized dwarfing rootstocks could be improved upon, and to this end work was begun on a joint project by the John Innes Horticultural Institute, then at Merton, England, and the East Malling Research Station. The EM series of rootstocks had proven to be susceptible to the Woolly Apple Aphid (WAA). Fruit growers in Australia were suffering considerable damage due to the WAA and the joint breeding project between Malling and Merton was directed at developing a WAA-resistant series of rootstocks. From the Malling-Merton research was born the "MM" series of size-controlling, WAA-resistant rootstocks. MM106 and MM111 are the two most commonly used rootstocks of the MM series. Trees planted on these two rootstocks are generally referred to as "semi-dwarf" trees because in size they are somewhat smaller than a seedling but larger than a fully dwarfed tree.

Until the 1960's, there was very little interest in tree size control on the part of U.S. growers. European growers adopted dwarfing rootstocks much earlier, in the interest of obtaining higher production from limited available land. In the United States, land was plentiful until very recently, and growers were reluctant to adopt different technology. In a report based on research conducted from 1964 to 1966, Snyder concluded that "Unless there is a decided advantage in yield and cost of production, the size-controlled tree may not be competitive with the so-far higher yielding standard apple trees" (Snyder, p.20). Thus, in the mid-1960's, growers were beginning to plant size-controlled apple trees, but they were not yet realizing the full potential in increased yields and decreased relative production costs that are available from higher density (more, smaller trees per acre) apple plantings.

As the decade of the 1960's came to an end, apple orchardists began to feel the same pressures that all of agriculture was experiencing. Higher costs, especially for labor, and product prices which were not rising as fast as costs, began to demand greater productive efficiency. It was widely believed that the use of dwarfing rootstocks and the switch to higher density plantings would lead to improved efficiency. More growers began to try higher density plantings, and with more experience and greater incentive to realize the potential efficiency of the new technology, higher density apple orchards came into their own in the 1970's.

The adoption of new technology brought with it a new set of problems. In a report published in 1974 Downy et al. concluded that

> ".....increased tree density on dwarfing rootstocks may result in increased production efficiency and profitability of the apple orchard. Analysis shows that orchard profitability tends to increase as tree density increases. However, the investment requirements and managerial skills necessary for successful production, increase with tree density" (Downy et al., p.20).

The industry was recognizing that higher density apple plantings had great potential, but that growers should exercise caution in making the jump from standard, full-size trees to high-density planting systems. In 1974, Funt reinforced this opinion: "The grower should be aware that planting a high density system means more risk than planting a medium density system. Researchers and growers have had so little experience with these systems that some serious problems remain to be solved and others may not even have been discovered." (Funt, p. 105).

In the 1980's, growers may choose among a wide variety of alternative apple planting systems, virtually all of which depend upon clonal rootstocks. Tree size control is the predominant reason for using clonal rootstocks, but there are other advantages:

1) Disease resistance - many clonal rootstocks are bred specifically for resistance to diseases.

2) Uniformity - with proper use of clonal rootstocks, it is possible to obtain an orchard containing trees of nearly identical size.

3) Adaptation - to specific environmental problems, such as soils that are poorly drained or that tend to be droughty.

The size controlling characteristic of many clonal rootstocks has attained significance in the apple industry for several reasons:

1) In general, better quality fruit with higher color is obtained with smaller trees. Better quality apples of superior color command higher prices.

2) Smaller trees are easier to prune, spray, and harvest than larger trees.

3) Less spray material is needed, on a per acre basis, because there is less tree volume per acre and adequate spray coverage is easier to obtain.

4) Orchards containing smaller trees require smaller, and hence less expensive, equipment.
5) Harvest labor is more readily available for trees which do not require ladders for harvesting. Harvesting efficiency is greatly increased on smaller trees.

6) The smaller trees, with some exceptions, tend to bear fruit earlier in their life cycle, which improves cash flow and profitability.

7) Smaller trees are generally more efficient in production, in that the maximum number of apples per number of growing points increases with decreased tree size.

As suggested earlier, plantings based on size-controlling clonal rootstocks tend to have the following disadvantages:

1) Monoculture - if a devastating disease or insect enters a planting, the problem may be intensified because the rootstocks were all cloned from the same "parent".

2) More Expensive - trees on dwarfing rootstocks cost more individually, and more of them per acre are required than in a planting of seedling trees.

3) The rootstock/scion combination must be matched to the climate and soil under consideration.

4) The productive life span of some of the newer rootstock/scion combinations is unknown.

5) Higher density planting systems require more intensive management. The higher the tree density in a planting, the more sensitive the planting is to cultural errors and climatic situations.

6) Use of extremely dwarfing rootstocks usually involves some form of tree support. Poles or trellis systems commonly used are relatively expensive.

Many growers have recently begun to exhibit a reluctance to establish high density apple plantings which require support systems. This reluctance is due to the relatively high cost involved in purchasing, installing, and maintaining tree support systems. Researchers have addressed this problem by developing a tree known as the "Interstem". Interstem trees consist of a well anchored rootstock which is planted in the ground, a center stem piece, and the scion, or top part of the tree which carries fruit of the desired cultivar. Good anchorage, provided by the rootstock used in the interstem trees, alleviates the necessity for tree support systems. Additionally, interstem trees can, within limits, be engineered to desired size by adjusting the length of the stem piece. A disadvantage of interstem trees is that they cannot be planted as close as fully dwarfed trees used in other high density systems.

There are four general planting systems being utilized by New York growers: Standard, Semi-Dwarf, Interstem, and Dwarf in descending order of tree size. General characteristics of these systems under New York conditions are shown in Table 1. The grower clearly has several tradeoffs to consider regarding the size of initial investment, the years to commercial yield, the yield at maturity, and fruit quality. Generally, the higher the initial investment the shorter the waiting time expected until a commercial crop is produced, the higher the expected yields and fruit quality at maturity and the greater the managerial skills required.

It is clear that a grower contemplating orchard replacement is faced with a baffling array of choices. The problem is complicated still further by the general lack of information concerning the newer planting systems. Cost information is needed for the various rootstocks, varieties, and planting systems currently available. Of even greater importance, yield data over the productive lives of the new planting systems would be helpful. Unfortunately, many of the planting systems are so new that no one knows their productive lives, and the "state of the art" in the apple industry is changing so rapidly that data collected on one system may be rendered obsolete by new systems before a complete data set is obtained.

Objectives

The general objective of this research is to analyze the two orchard replacement questions for apples grown in New York State:

1) When should the current orchard be replaced?

2) With what system should the current orchard be replaced?

In meeting the general objective, two subobjectives are also met:

1) The development of a user-friendly, easily-accessible computer model which can answer the two questions for an individual grower's orchard.

2) Use of the model developed to analyze the replacement decision under various economic and pomological conditions.

With these objectives in mind, the rest of this report includes a review of the theoretical framework for developing the replacement model; a step by step presentation of the model; sensitivity analysis on selected variables using the model; and a summary, conclusions, and statement of the limitations of the decision model.

Table 1. Characteristics of The Four Apple Planting Systems Commonly Found in New York State

System	Planting Density Trees/Acre	Required Initial Investment Per Acre	Years to Commercial Production	Mature Annual Yield Per Acre (bu.)	Fruit Quality*
Standard	27-121	$1,200-2,200	7 - 8	300 - 800	4
Semi-Dwarf	100-200	$1,800-2,800	5 - 6	500 - 1,000	3
Interstem	150-300	$1,900-2,900	4 - 5	600 - 1,200	2
Dwarf	300-500	$3,300-5,500	3 - 4	600 - 1,200	1

* 1 = highest quality fruit
4 - lowest quality fruit

THEORETICAL BASIS OF THE REPLACEMENT MODEL

The apple grower considering replacement of a block or an orchard of trees faces a unique type of investment decision. The grower can choose to retain the current planting for a few more years and collect a stream of revenue which will presumably be either constant or decreasing, at least in real dollars. Alternatively, the grower may choose to establish a new planting of trees of the same or of a different type. If the choice is replacement, there will be a period of years during which there is a net cash outflow since the new trees must be maintained prior to beginning their productive lives. Thus, the grower must somehow choose between retaining the current stream of net cash inflows or making a large initial cash outlay, followed by a few years of expenses with little cash inflow, until finally the new trees come into full production.

The first problem lies in making the comparison between current dollars and future dollars. This problem has been approached by utilizing the concept of discounting. Using discounting, a stream of annual cash flows, whether net inflows or net outflows, can be converted to a net present value. Algebraically, the net present value of a stream of cash flows is defined as:

$$(1) \qquad A = \sum_{t=0}^{T} \frac{C_t}{(1 + r_t)^t} \text{, where}$$

C_t = the cash flow in year t,

r_t = the rate of interest (discount) in year t,

t = 0, 1, 2, 3, ..., T, and

T = the last year of the planning horizon.

The net present value equation has several implications. Most serious consideration must be given to r_t, the discount rate. The determination of r_t is made by an individual and is based upon the assumption that a dollar today is worth more than a dollar tomorrow. Aside from pure time preference, a dollar in the future is worth less than a dollar today for two important reasons.

First, there is an opportunity cost associated with giving up current dollars for future dollars. There are always other ways to use money currently held. It can be used for current consumption or it can be invested for some rate of return, but in either case the cost of lost opportunity must be considered when deciding whether or not to make an investment.

Secondly, there is always some degree of risk associated with any postponement of current consumption or investment. An orchard is probably less risky than drilling wildcat oil wells, and it is not as safe an investment as U.S. government bonds. An individual, in determining a discount rate, should choose the rate of return from an investment which in his or her best judgement has a risk factor similar to that of an orchard. For example, if the rate of return on a particular Blue Chip stock were 11 percent and the analyst felt that the chances of an orchard failing entirely were about the same as those for the Blue Chip stock, then 11 percent would be that person's discount rate.

It should also be noted that r_t can be different for each year t. This may be due to changes in perceptions regarding the opportunities available in future years, or it may be due to an idea that orchards might be more or less risky investments in a few years. It may also be an adjustment for expected future rates of inflation.

This introduces another aspect of r_t. If r_t is a discount rate which is inflation-free, then it is called a "real" discount rate. If r_t includes some expected inflation, it is referred to as a "nominal" discount rate. Algebraically:

$$(2) \quad 1 + r_t = \frac{1 + n_t}{1 + i_t}, \text{ or } r_t = \frac{1 + n_t}{1 + i_t} - 1, \text{ where,}$$

r_t = real discount rate,

n_t = nominal discount rate, and

i_t = rate of inflation.

If real cash flows are being used in an investment analysis, the real discount rate should be employed; if nominal cash flows are utilized, the nominal rate of discount is correct. In this analysis, real discount rates are used with real cash flows. Adjustment is made for risk in the sensitivity analysis by varying yields and quality.

One further observation on the net present value formula is that as t becomes large, the cash flows in periods farther in the future are discounted more heavily. The implication for orchard replacement is that, the sooner an orchard can generate a positive cash flow, and the larger the positive cash flows, the more valuable that orchard will be, ceteris paribus.

When one has determined the expected stream of cash flows for each of several alternative orchard planting systems, and a rate of discount has been established; a choice must be made among the alternatives. One method of doing this is to employ the net present value (NPV) concept. A choice is made by computing the NPV over the expected life of each alternative, and rejecting those alternatives for which the NPV is negative using the chosen discount rate.

Another means of evaluating alternative investments which enjoys wide popularity among business executives and which could be applied to the selection of the best among many orchard planting systems is the Internal Rate of Return (IRR) method. The IRR approach is considered by many people to be easier to visualize than the NPV method since it is not necessary to prespecify a discount rate.

The IRR method involves finding the rate of discount such that net present value is equal to zero. IRR is computed for each alternative investment, and only those investments with IRR <u>higher</u> than some predetermined rate, in this case the inflation-free opportunity cost of capital are considered. Algebraically:

$$(3) \qquad A = \sum_{t=0}^{T} \frac{C_t}{(1 + IRR)^t}$$

where A = net present value = 0

C_t = cash flow in year t,

IRR = the rate of discount,

t = 0, 1, 2, 3, ..., T, and

T = the last year of the planning horizon.

The solution can only be found by trial and error.

The IRR rule has the following limitations (Brealey and Myers):

1) If positive and negative cash flows alternate, year to year, the IRR rule gives either a meaningless rate of return or multiple rates of return, depending upon the magnitude of the various cash. flows. Sometimes there is no IRR at all.

2) If, as with apple orchard replacement, the investment projects are mutually exclusive, the IRR rule cannot necessarily be used directly to rank the investments or choose between them. The IRR criterion is misleading, since at some discount rates it will lead to selection of the investment which does not have the highest NPV

3) Finally, another problem with the IRR decision criterion occurs when one cannot make the assumption that interest rates are constant over time. When interest rates are not constant, there is not a unique IRR.

The use of NPV avoids all of the aforementioned pitfalls. Changes in signs in the cash flows do not affect the validity of the final result; it is capable of handling multiple rates of discount; and investments that are mutually exclusive can be ranked merely by choosing the one with the highest net present value. For all of the above reasons, the IRR approach is discarded as an alternative in this analysis.

The problem of orchard replacement is not entirely solved, however, with the choice of the NPV method of evaluating alternative orchard planting systems. Analysts, for the last 20 years, have been unable to apply the net present value approach directly to the problem of timing of orchard replacement.

Direct application of the NPV rule depends upon the ability to accept investments (planting systems) for which the computed NPV is zero or positive. For example, if a grower with vacant land were presented with several alternative new orchards having different expected cash flows but equal expected productive lives, the NPV criterion could be applied directly, and the choice could be made to plant the orchard with highest NPV.

If, however, the situation involved an established orchard of age 25, the added dimension of timing is introduced and the problem becomes one of replacement. The replacement problem involves answering two questions: When to replace, and with what? Assume for the moment that the appropriate replacement orchard has already been chosen, and that only the question of when to replace remains unanswered. In this case, direct application of the NPV criterion would suggest a comparison of the NPV over the remaining years of economic life of the established orchard with the NPV of the replacement orchard. NPV cannot be used directly because there are two distinct time horizons. The established orchard has relatively few years left in its economic life, whereas the replacement orchard has a full economic life ahead. Unless the two time horizons are equal, the NPV criterion will not be able to fairly choose between keeping the established orchard and replacing with a new orchard.

Average Annualized Net Revenue

A procedure is needed for fairly comparing the stream of expected cash flows from the current orchard with the stream of expected cash flows from the replacement orchard. Economists have utilized a methodology which converts the stream of expected cash flows from the replacement orchard into "average annualized net revenues" (AANR). The AANR method was first applied to the orchard replacement problem in a report on cling peach tree replacement by Faris. Faris and Reed published a circular for the purpose of aiding growers in making the cling peach tree replacement decision based on the earlier work by Faris. The concept was also utilized by Perrin and Proctor in a guide for the replacement of apple trees, by Khera and Crowe in what is perhaps the most definitive work on apple tree replacement to date, and by Gerling, also in the context of apple tree replacement.

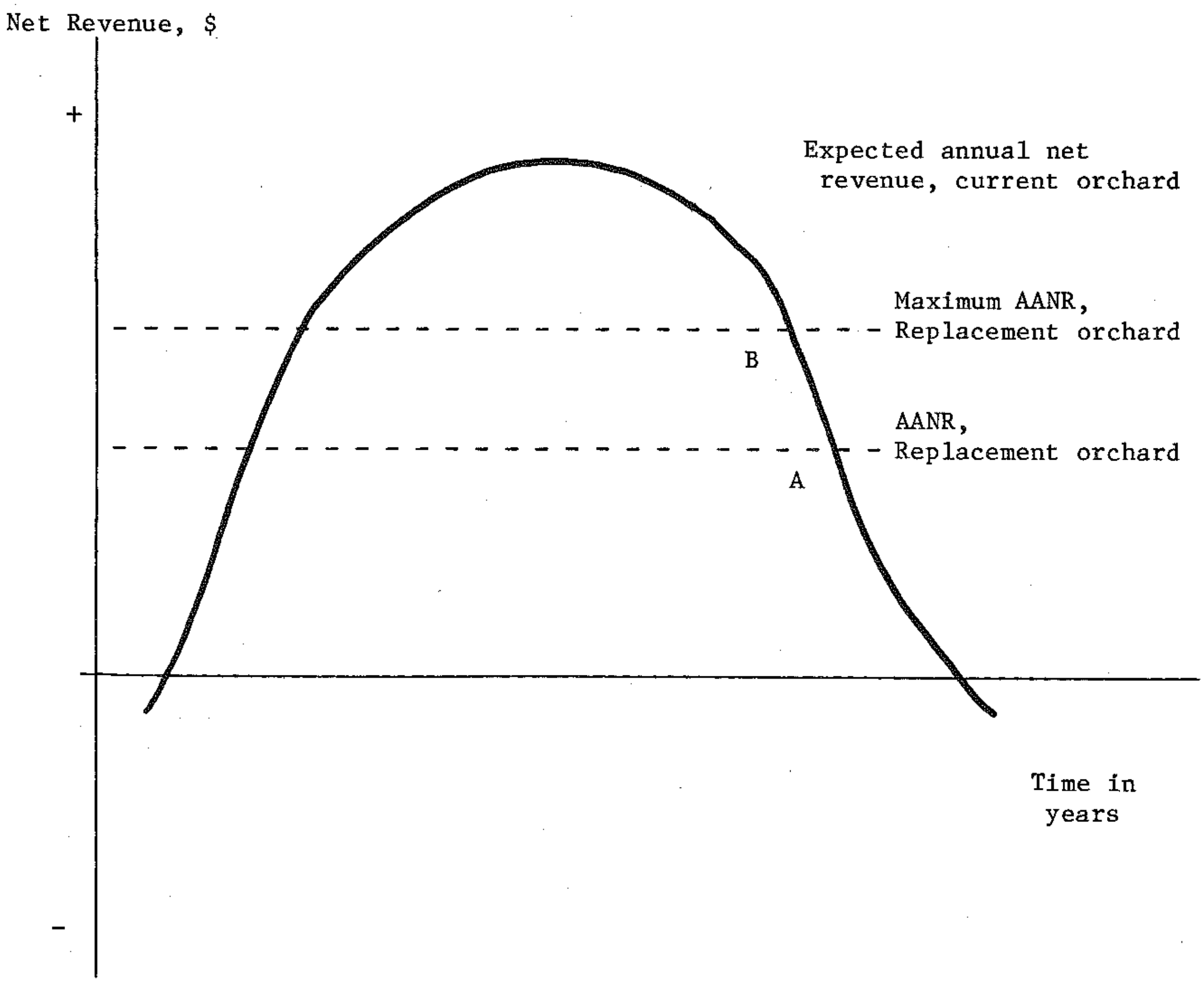
There are two ways in which the AANR approach is used. In the first case, employed by Perrin and Proctor, Gerling, and Khera and Crowe, AANR is calculated by setting a lifespan for the replacement orchard, and then amortizing the NPV of the orchard over its chosen life, using the annuity factor. For example, if an NPV of $1,500 per acre is calculated from the projected cash flows of a replacement orchard which is presumed to have an economic life of 30 years, its AANR is:

$$\$1,500 \left[\frac{1 - (1+r)^{-n}}{r} \right]^{-1} = \$1,500 \left[\frac{1 - (1.12)^{-30}}{.12} \right]^{-1}$$

= $186 per acre with a discount rate of 12 percent. The decision rule in this case says that if the expected net revenue next year for the current orchard is less than $186, replace the orchard (Figure 2, point A).

In the second case, used by Faris and Reed and by Bauer, Rathwell, and King in the analysis of peach orchards, AANR is calculated for each year in the life of the replacement orchard. The expected annual net revenue from the current orchard is then compared to the maximum AANR from the replacement orchard. The orchard should be replaced when expected net revenue for the next year is less than the maximum AANR from the replacement orchard. For example, if the replacement orchard has expected net revenues as indicated, and if the discount rate is 11 percent, the methodology proceeds as follows:

Figure 2. Graphic Representation of the Average Annualized Net Revenue (AANR) Replacement Methodology



Year	Net Revenue	Annualized Average Revenue @ 11 Percent	Accumulated NPV
.	.	.	.
.	.	.	.
.	.	.	.
13	$1,800	$172	$ 700
14	1,000	199	1,164
15	800	217	1,396
16	600	227	1,563
17	400	231	1,744
18	300	232	1,790
19	200	231	1,818
20	50	229	1,824
.	.	.	.
.	.	.	.
.	.	.	.

The optimum in this case is obtained in the 18th year in the life of the orchard, at maximum AANR of $232 per acre (illustrated by Figure 2, point B). Using this variation of the AANR approach is more critical for peaches than for apples, since peaches can experience a pronounced yield decline in the later years of their lives, whereas apple yields tend to decline gradually with age.

There are drawbacks to using the AANR methodology, especially in light of recent developments in computer technology. First, the use of AANR assumes that a replacement orchard has already been chosen. There is no provision within the methodology, besides exhaustive enumeration, for choosing the best among several alternative orchard planting systems. This choice must be made prior to determining the optimum replacement time, and it would probably be made based on a comparison of net present values for the alternative orchards. In this case, a methodology which could optimize both the time of replacement and the replacement system simultaneously would be superior.

Secondly, the AANR method requires comparison of an actual or expected cash flow with an average cash flow. On the one hand, the average cash flow figure is some distance from reality since it is used to "smooth" a lumpy stream of cash flows over a large number of years. On the other hand, the use of expected cash flows based on last year's experience or on the experience of other growers may be misleading if, for example, there have been a series of extremely poor or extremely good years in the business. If a grower had just experienced four very poor years, he or she may assume that next year's revenue will also be poor, and the AANR criterion could suggest replacement in the year just prior to a long upswing in orchard profitability.

The third problem with the AANR method is that it is essentially a static analysis. It requires viewing the entire lifespan of both the current and the replacement orchard in a snapshot, as in Figure 2. In order to more closely approach reality, a different snapshot of both the current and replacement orchard systems must be taken each year, under the conditions prevailing in that year. Prices, inflation, and expectations change from year to year. While no analyst can predict the future, a dynamic decision framework allows more flexibility in the possible course of future events. The AANR approach only allows the grower to make the replacement decision year by year. There is no provision for what decision should be made, for example, five years from now.

Dynamic Programming

There is a technique available which can solve the problem of when to replace an orchard and choose the best among several alternative replacement planting systems, while exhibiting none of the previously discussed undesirable characteristics of the AANR method. This technique is known as "dynamic programming".

Dynamic programming is a general mathematical approach that can be used to solve a variety of problems having certain characteristics (Hillier and Leiberman, Bellman, and Howard). A problem that can be solved using dynamic programming must have the following characteristics:

1) The problem can be divided into stages. In this case, the stages are years in which the orchard could be replaced. A policy decision is necessary at each stage. For this problem, the policy decision at each year in the life of an orchard is whether or not to replace.

2) Each stage has states associated with it. The states are usually the various conditions in which the system could exist at a given stage. For this problem the state is the age of an orchard in a given year.

3) At each stage, the policy decision transforms the system into a state associated with the next stage. With an orchard, if the current orchard is 15 years old in year three (stage 3) then a decision to "keep" the orchard will result in a 16-year-old orchard in year four. If the decision is to "replace" the orchard, the state in stage four will be a new orchard.

4) An optimal policy for all remaining stages is independent of the policy decisions made in previous stages. This is known as the "principle of optimality" or the "Markovian Property". In the replacement case, this means that in the current state it is unknown which system of what age was replaced that led to the current state.

5) The solution procedure begins at the final stage, finding the optimal policy for each state of the last stage, working backwards until the optimal policy is found for the first stage. The backward-moving solution procedure is based upon a recursive relationship which identifies the optimal policy for each state of stage t, given that an optimal policy for each state at stage (t+1) exists. A general form of this recursive relationship is:

4: $J^*(y_t) = \max./\min_{u_t}. \; [I_t(y_t,u_t) + J^*_{t+1}(y_{t+1})]$

where

u_t = a vector of control variables;

y_t = a vector of endogenous variables;

$J^*_{t+1}(y_{t+1})$ = the value or cost of the optimal trajectory from y_{t+1} to y_T, where T = terminal time;

$I_t(y_t, u_t)$ = the value or cost of implementing control strategy u_t to go from y_t to y_{t+1}

While the backward-moving solution procedure works well for a certain class of problems, there are occasions when this method becomes unwieldy. If, for example, a problem has many stages and/or many states, which is the case with the orchard replacement problem, the search procedure for an optimal policy for each state of each stage becomes lengthy, and vast amounts of storage space are required for all of the information generated as the solution procedure moves toward the initial stage. This problem is referred to as the "Curse of Dimensionality".

Other solution techniques have been developed for solving dynamic programming problems of a specific type. Howard developed an approach that can be used when the following conditions are met:

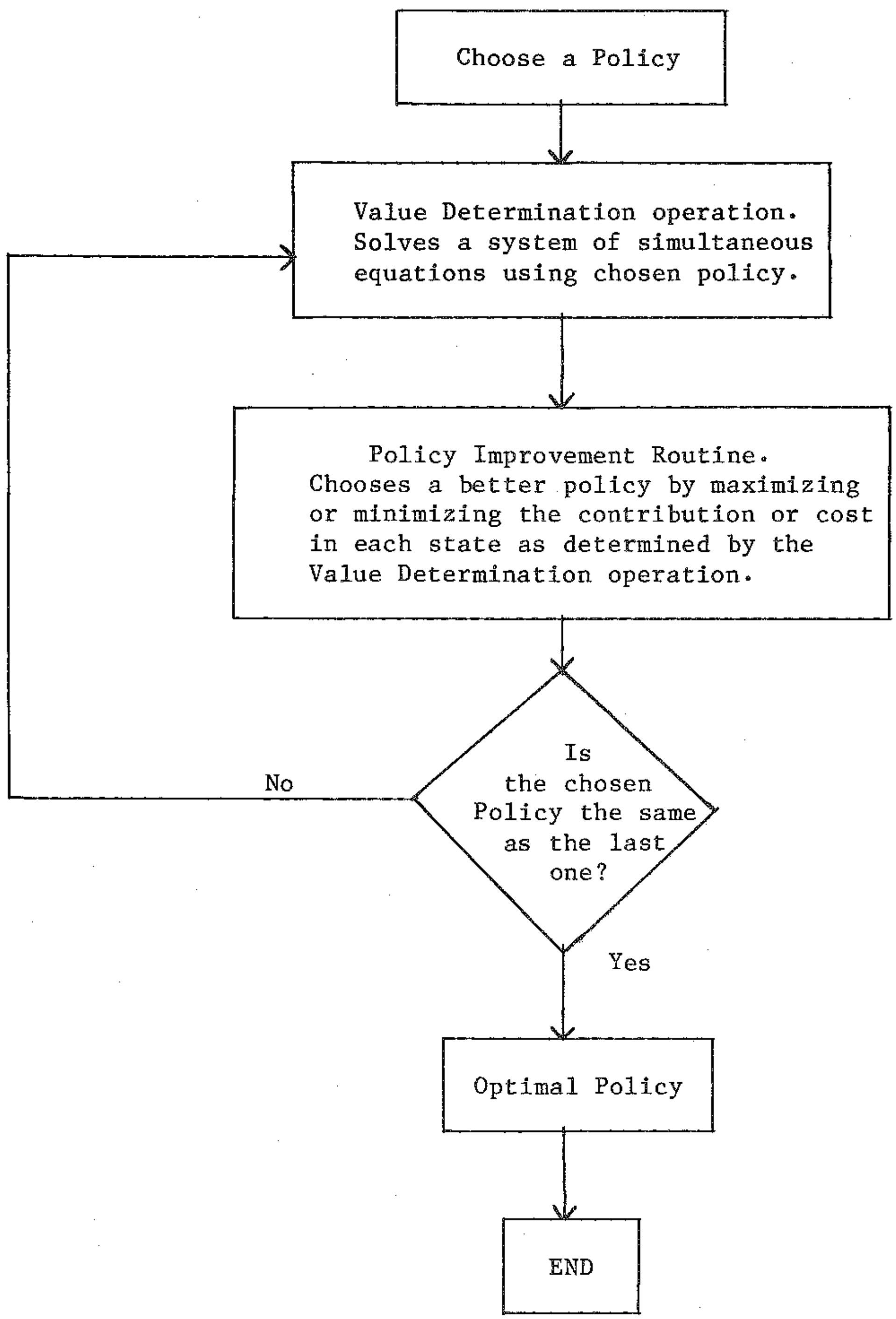
1) The same states are present in each stage.

2) For each decision in each state of each stage, movement to the next stage is determined by a vector of probabilities. The vector of probabilities is a row of transitional probabilities from a Markov transitional probability matrix (Hillier & Lieberman).

3) There are a large number of stages.

The Howard approach to dynamic programming uses the Policy Iteration method for finding an optimal solution. The Policy Iteration method is a two step procedure involving the solution of a set of simultaneous equation rather than working backward to a final solution as described above. The Policy Iteration method consists of a Value-Determination operation and a Policy Improvement routine (Figure 3). The Value-Determination operation solves the system of simultaneous equations using one chosen policy. Then the Policy Improvement routine uses the vector of solutions to the simultaneous equations found in the Value Determination operation to determine a better policy, by maximizing or minimizing the cost or contribution in each state. The maximum or minimum cost or contribution thus found for each state becomes a new policy, and the Value Determination operation is repeated, followed by the Policy Improvement routine. When the iterations of Value Determination followed by Policy Improvement converge to identical policies for successive iterations, the optimal policy is found.

Figure 3. The Howard Policy Iteration Approach to Dynamic Programming



The Howard approach to dynamic programming has been applied to machinery replacement (Harsh and Milligan). The orchard replacement problem also has the characteristics necessary for solution by the Howard approach. The full model and its specific application to orchard replacement are described in the next section.

THE MODEL

The proposed orchard replacement model consists of two components, which work together to form a computerized decision aid. The first component is a simulation model designed to produce an after-tax cash flow for each year in the economic life of the standard, semi-dwarf, interstem, and dwarf planting systems described previously in Table 1. The second component is a dynamic programming model which uses the after-tax cash flows produced by the simulator to determine the optimal replacement time and the optimal planting system. The model uses an infinite planning horizon, but assumes that the maximum economic life of all four systems is 30 years, forcing replacement in the beginning of the 31st year.

The Simulation Model

The purpose of the simulation model is to generate an after-tax cash flow for each of the 30 years in the life of each of the four general planting systems being analyzed. The model was programmed in an interactive, question-and-answer mode, to enable a person with limited knowledge of computers to use it. The model is very simple to operate; however, a user desiring to change all 28 input quantities for all 30 years in the lives of all four planting systems could find the process time consuming.[1]

This orchard replacement model was designed to allow maximum flexibility. Each user has the option of employing data specific to an orchard, or of utilizing the data which is stored in the model. The stored data describes a representative 55 acre orchard for New York State. This data set is based on recent work by Whitaker. Necessary modifications of Whitaker's work to meet the objectives of this analysis are the result of conversations with growers, agricultural economists, and pomologists. It is recommended that growers carefully analyze the stored data and modify it in such a way that it reflects, with some accuracy, the unique characteristics of the particular orchard under consideration.

The complete stored data set is in Childs. Input prices, packouts, and variable costs are summarized in Table 2. The representative machinery complement consists of two tractors (60 h.p. and 30 h.p.). These two tractors are used for different operations appropriate to their relative size for the standard, semi-dwarf, and interstem plantings, while the small tractor is used for all operations in the dwarf planting. In addition to the tractors, there are an herbicide sprayer, a fertilizer applicator, and two sprayers. Also assumed are an irrigation pump, an established well, and sprinklers with sufficient pipe. Harvest equipment costs are included in the per bushel harvest cost.

Only variable or operating costs, such as fuel, lubrication, and repairs and maintenance, have been included for the machinery. Fixed costs are not included since these costs are not affected by the replacement decision. It is assumed that no change in the machinery complement is required because of

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[1]If the model were adapted to another computer system, with different visual capabilities, the time required for changing all inputs to fit a particular orchard could be reduced substantially.

Table 2. 1980 Capital Investments, Prices, Packouts, and Variable Costs per Acre

A. Input Prices

	Item	Price
1.	Hourly wage rate	$ 4.60
2.	Hourly rate for mower	1.79
3.	Herbicide 1 cost (materials)	5.76
4.	Insecticide cost (materials)	5.90
5.	Fungicide cost (materials)	5.60
6.	Thinning spray cost	10.00
7.	Alar cost	31.00
8.	Ethrel cost	5.50
9.	Fertilizer cost	55.00
10.	Beehive rental cost	25.00
11.	Hourly rate for small tractor	3.25
12.	Hourly rate for large tractor	5.40
13.	Hourly rate for herbicide sprayer	.35
14.	Hourly rate for tree sprayer (large)	5.90
15.	Hourly rate for fertilizer applicator	.30
16.	Mousebait cost	3.30
17.	Irrigation water cost, $/acre-foot	50.00
18.	Irrigation pumping cost, $/acre-foot	125.00
19.	Pruning equipment cost for year	5.00
20.	NAA materials cost	18.00
21.	Herbicide 2 cost (materials)	5.76
22.	Hourly rate for small tree sprayer	4.00

Table 2. continued

B. Planting Density Harvest Costs

System	Tree Type	Trees per Acre	Per Bushel Harvest Cost
Standard	1	121	$1.65
Semi-Dwarf	2	218	1.55
Interstem	3	218	1.45
Dwarf	4	454	1.35

C. Investment in Planting and Development

Tree Type	Removal	Fumigation	Preparation	Tree Purchase	Planting	Training	Other
1	$300	$500	$240	$ 485	$120	$20	$ 50
2	300	500	240	1,035	120	30	50
3	300	500	240	1,145	120	30	75
4	300	500	240	2,160	120	50	1,950

D. Apple Prices, Net of Packing and Other Charges per Bushel, 1981 (New York State Averages)

Grade	Price
Cell Pack	$7.65
Bag	4.75
Juice	1.65
Cull	.10

E. Quality Distribution, by Tree Type, as Percent of Total Yield

	1	2	3	4
Cell Pack	50%	60%	65%	70%
Bag	24	24	20	20
Juice	25	15	14	9
Cull	1	1	1	1

Table 3. Input Items Required to Compute After-Tax Cash Flows.

A. Cultural Operations: For each tree type, for each of 30 years;

Item	Labor	Machinery	Materials	No. of Applications
1. Pruning	X	X		
2. Mowing	X	X		X
3. Herbicide I	X	X	X	X
4. Herbicide II	X	X	X	X
5. Insecticide	X	X	X	X
6. Fungicide	X	X	X	X
7. Thinning Spray	X	X	X	
8. Stop-Drop Spray	X	X	X	
9. Ripening Agent Spray	X	X	X	
10. Fertilizer & Lime	X	X	X	
11. Bee Hives			X	
12. Mousebait	X	X	X	X
13. Irrigation	X	X	(water)	X
14. N.A.A.(Sucker Control)	X	X	X	X
15. Miscellaneous	X	X	X	

B. Harvest Costs Per Bushel

C. Cultural Costs

1. Hourly wage rate
2. Hourly rate for mower
3. Herbicide I materials cost
4. Insecticide materials cost
5. Fungicide materials cost
6. Thinning spray materials cost
7. Stop-drop spray material cost
8. Ripening agent material cost
9. Fertilizer cost
10. Bee hive cost (per season)
11. Hourly rate for small tractor, if applicable
12. Hourly rate for large tractor, if applicable
13. Hourly rate for the herbicide sparyer
14. Hourly rate for tree sprayer
15. Hourly rate for fertilizer applicator
16. Mousebait material cost
17. Irrigation water cost, $/acre foot, if applicable
18. Irrigation pumping cost, if applicable
19. Pruning equipment cost per year
20. N.A.A. (Sucker control) material cost
21. Herbicide II material cost

Table 3 continued

D. Packout, percent, by tree type

1. Cell pack
2. Bags
3. Juice
4. Cull

E. Expected farm gate price (wholesale price net of packing, storage, shipping, and handling) for each grade denoted in (IV) above.

F. Investment in Planting and Development, by tree type, including:

1. Tree removal
2. Fumigation, if necessary
3. Purchase of new trees
4. Planting
5. Training
6. Land preparation
7. Other

G. Yield, by tree type, for each year in the designated 30 year lifespan of all tree types.

H. Tax Bracket, current or expected, if change is anticipated.

I. Cost Recovery Schedule (depreciation). Operator can choose a 5, 12, or 25 year cost recovery period.

J. Discount Rate. This is an inflation-free discount rate. (see text)

Figure 4. Diagramatic Representation of the Simulation Model.

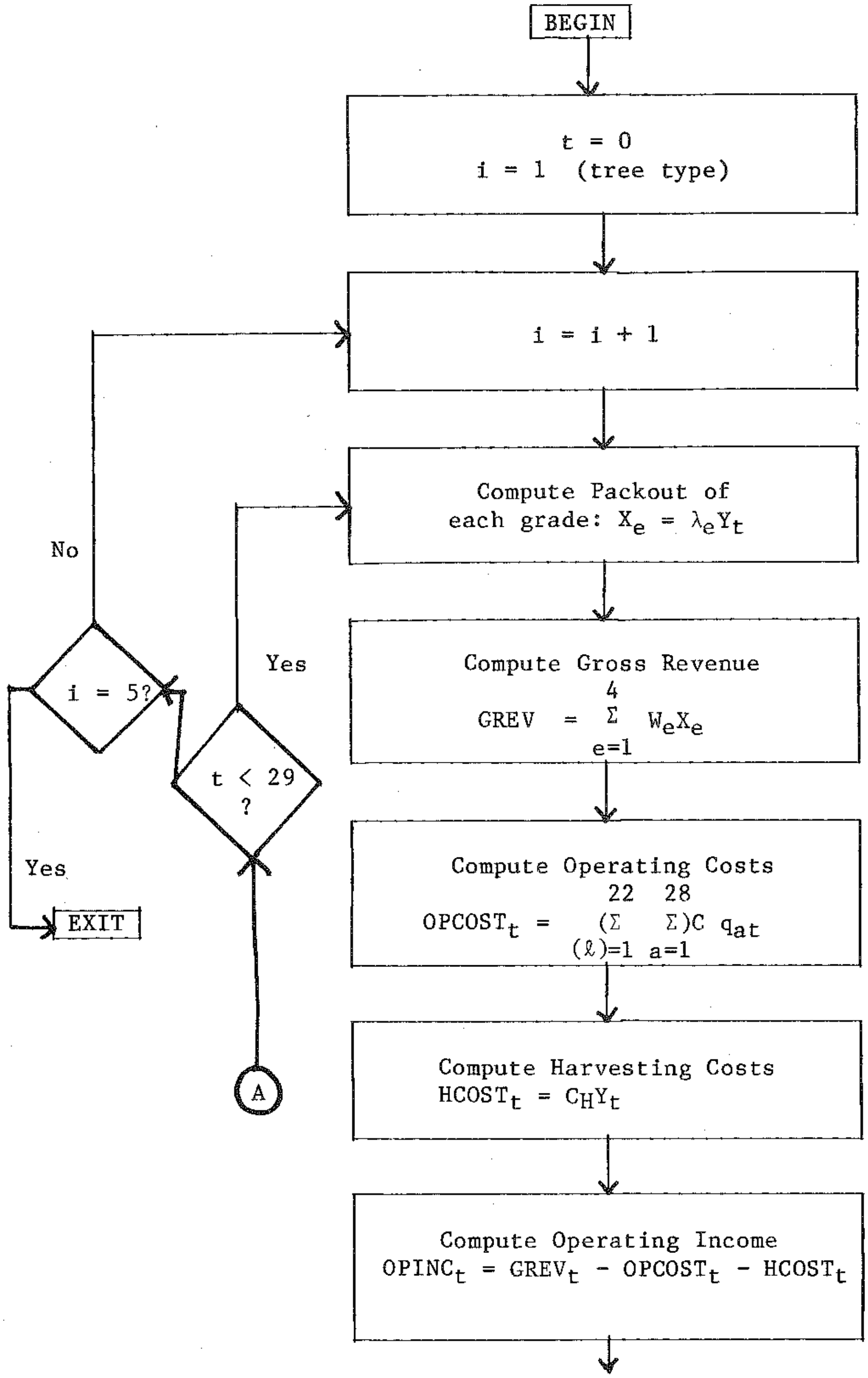

Figure 4 continued

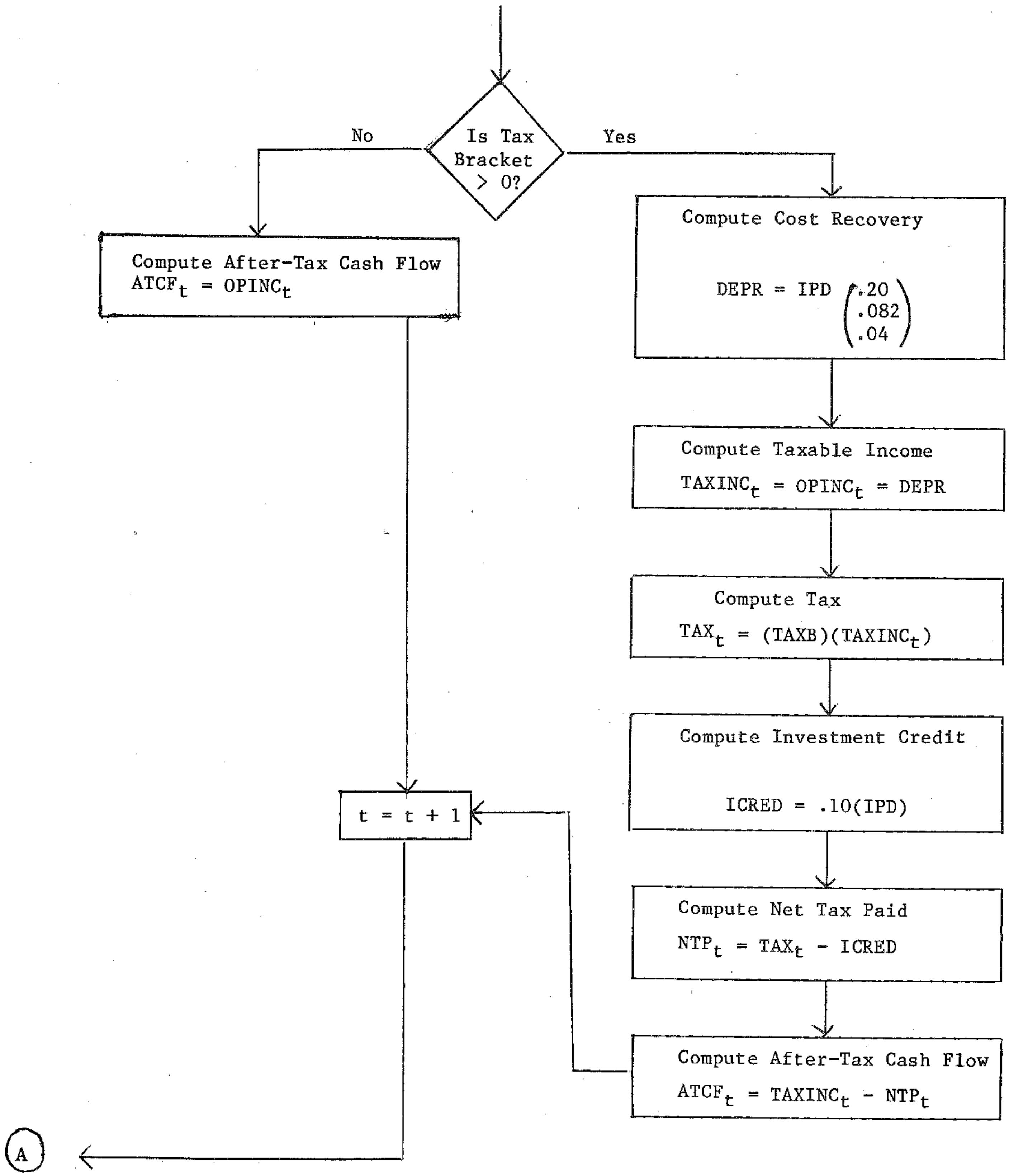

Table 4. Definition of Variables Used in the Simulation Model.

The operator selects, for each tree type:	Variable
1. Input quantities for cultural operations	q_{at}
$a = 1, \ldots, 28$ input quantities $t = 0, \ldots, 29$ years	
2. Input prices	C_{ℓ}
= 1, ..., 22 input prices	
3. Harvest cost per hushel	C_H
4. Percent packout, by tree type	λ_e
$e = 1, 2, 3, 4$ quality grades	
5. Expected farm gate price (wholesale price net of storing, packing, shipping, and handling) for each grade in (4) above.	W_e
$e = 1, 2, 3, 4$ prices by grade	
6. Investment in planting and development, by tree type	IPD
7. Yield, in bushels per acre, by tree type	Y_t
8. Tax Bracket	TAXB
9. Cost Recovery Schedule	5, 12, or 25 years

a particular replacement decision.

Under "Investment in Planting and Development", the "Other" category for dwarf trees of $1,900 represents the cost of the trellis or pole support system required for dwarf plantings, while the remaining $50 represents miscellaneous establishment costs (Table 2C). Harvest costs are based on Gerling, with adjustments for the fact that ladders are not required on higher density systems, which increases the efficiency of harvest labor, and reduces harvest costs.

It must be recognized that as orchard planting density increases, more intensive management is required, but for most growers this is a qualitative rather than a quantitative decision variable. Management expenses are typically included when developing production cost budgets for various crops. The management charge is used as a means of placing a value on the operator's managerial time, but it is seldom an actual cash flow. Since this replacement model is based on actual cash flows, management charges were not included in the analysis.

Interest on investment is not included as a cost in the model because all cash flows are discounted within the model. The fact that interest payments affect after-tax cash flow can be accounted for by adjusting the discount rate by the expected marginal tax rate to obtain an after-tax discount rate.

Interest on operating capital is not included in this analysis. Individual growers may place actual or expected interest on operating capital expenses in the "miscellaneous" category in the model.

Inputs

The model requires the following data:

1) Quantities of inputs for all cultural operations including hours necessary for the performance of each operation (mowing, pruning, etc.), the quantity of spray materials used for each spraying, and other inputs such as beehive rental (Table 3A).

2) Input prices for all cultural operations including hourly charges for labor, tractors, sprayers, and other machinery, and per unit charges for input items (spray materials, fertilizer, etc.) (Table 3C).

3) Harvest cost, per bushel (Table 3B).

4) Percent packout for each of four grades by tree type. Determination of percent packout involves a judgement of the average quality of fruit that each tree type is capable of producing. The four designated grades are cell pack, bags, juice, and culls (Table 3D).[2]

5) Expected farm gate price, by grade. This price should reflect the

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[2]"Cell Pack" here refers to Fancy or Extra Fancy grade apples. "Bags" may be Fancy or No. 1 grades. The major difference is color. "Juice" apples are made into juice, and "culls" are discarded.

user's judgement of long-term wholesale prices, net of storing, packing, handling, and shipping charges.

6) Total investment cost in planting and development. Components are listed in Table 2.

7) Yield, in bushels per acre, by tree type. In this model, the grower has the option of changing each yield over the 30-year economic life of each orchard, adjusting the stored yield curves to better reflect a specific situation or of simply using the stored yield curves.

8) Tax bracket.

9) Cost recovery schedule. The operator can choose a 5, 12, or 25-year cost recovery period.

10) Real Discount rate.

The simulation model uses all of the inputs in the previous section to calculate after-tax cash flow for each of the four planting systems for each of 30 years. The calculations are shown diagrammatically in Figure 4 with variables defined in Table 4.

While the essence of the simulation model is shown in Figure 4, one special feature of this model is the inclusion of the effect of taxes on the replacement decision. Taxes are included following the Economic Recovery Act of 1981.

Orchardists have two basic choices regarding cost recovery. In the first case, the operating expenses are treated as expenses during the non-bearing years and are subtracted from the grower's other income. The expenses for planting and for purchase of trees in the establishment year are depreciated from the first year of commercial production for 5, 12, or 25 years, according to grower preference.[3]

In the second case, a grower may choose to accumulate all of the orchard operating expenses during the nonbearing years. When the orchard reaches commercial production, the initial planting expenses and the cost of trees is added to the accumulated operating expenses, and the total is depreciated from the first year of commercial production for 5, 12, or 25 years, according to grower preference. This alternative is not considered because it would rarely be optimal under current tax laws.

If a user enters a "zero" tax bracket, there is no cost recovery, and after-tax cash flow is equal to before-tax operating income. If a positive tax bracket is entered by the user, the second cost recovery option is automatically implemented, and the operating expenses during nonproductive years are treated as expenses.

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[3]Under the Economic Recovery Act, farmers have several options for cost recovery (depreciation) on orchards. For simplicity in modeling and to use the option most likely, in the author's judgement, to be used by farmers, the Straight Line method of cost recovery is included in this model. Under the Straight Line method, farmers may choose a five, 12, or 25 year cost recovery period.

Investment credit is defined by the Economic Recovery Act as 10 percent of the establishment costs, and can only be taken in the first year of commercial production. In the model, under any positive tax bracket, investment credit is subtracted from the income tax bill in the first year of commercial production. For a "zero" tax bracket, investment credit is not included in the analysis.

Yields

One of the most important determinants of orchard profitability, and a factor which must weigh heavily in the orchard replacement decision, is the potential ability of an orchard to yield large quantities of good quality fruit, on a sustained basis. There is a general lack of available time series data on orchard yields, especially for the newer planting systems.

As mentioned in the introduction, plantings using dwarfing rootstocks, either with support systems or on interstems, are a relatively recent phenomenon, so that little yield information over long periods of time is available. Most growers have subjective estimates of yields by variety and planting system in their orchard blocks, but because of the intricacies of the packing and storage process, exact yield records on individual blocks of trees are usually not obtainable. There is also the problem of changing technology. Researchers are reluctant to devote 20 or 30 years to collection of information about a system which may be obsolete by the time the data are collected. Data are becoming available, however.

The yield data used for this project are part of the data collected for the 1980 New York Orchard and Vineyard Survey, published in 1982, and were provided by Glenn Suter, Statistician in Charge, and Scott Painter, Systems Programmer, New York State Department of Agriculture and Markets, Division of Statistics.

The data were assembled using the form shown in Figure 3. The rootstocks given were separated into the four broad categories designated in this project. The rootstocks designated "Standard" were placed in the "Standard" category for the model. There were five rootstocks comprising the "semi-dwarf" category: M-2, M-7, MM-106, MM-111, and M-26. Interstem 9/106 and Interstem 9/111 were placed in the "Interstem" category for the model. M-9's were placed in the "Dwarf" category.

Data from over 9,000 orchard blocks throughout New York State were collected. Because of the form of the questionnaire and the type of information requested, the actual number of observations available for analysis was substantially lower. Since only tree numbers by age category and total production by rootstock were reported, it was necessary to remove all questionnaires from the data set upon which more than one age category per rootstock was reported. The remaining data facilitated computation of the yield/tree in such a way that a yield figure could be matched directly with a rootstock and age of planting. The final data set contained 3,877 observations on standard trees, 1,090 observations for the semi-dwarf trees, 210 for interstem, and 53 for dwarf.

In any data set of this size, there are observations which are unrealistically large or small because of errors in reporting, transcribing, typing or measurement. For each of the three remaining data sets, all observations greater than two standard deviations from the mean yield for a planting system were removed. This operation left 3,821 observations for the standard system, 999 for semi-dwarf, and 129 for the interstem planting system. The "dwarf" data were dropped from this analysis, because there were too few observations in some age groups of the dwarf data, and too many outliers to provide acceptable yield curves. For this reason, the interstem yield curve was used for both interstem and dwarf yields.

In order to perform Ordinary Least Squares (OLS) regression analysis on these data, the midpoint of each of the age categories in Figure 5 was designated as the age of the trees corresponding to the reported yield in that age category. For example, yields reported for standard trees in the seven to 11 age category were considered to be from nine year old trees. Age for the last age category, "22+", was set at 30 years. Because of doubts about whether zero observations in the first age category, "1-3", meant a yield of zero or a missing observation because a grower neglected to answer the question, the first age category was dropped from the analysis. An OLS regression then was run on four age categories and various numbers of observations on yield for three planting systems.

Six functional forms were hypothesized: logarithmic, logarithmic with a linear term, logarithmic with a quadratic term, logarithmic with a linear and quadratic term, quadratic, and quadratic with a linear term.[4] Checking the six estimated equations for significance of coefficients by comparison of t-ratios, all of the above functional forms were eliminated except the quadratic with a linear term. The quadratic with a linear term was used in estimating all three yield functions.

There are other econometric problems associated with this estimation of yield curves. First, there are only four data points upon which to base the estimation of a curve covering 30 years. This problem could be alleviated by the collection of more data over a period of years or by the addition of perhaps one more age category in the next orchard and vineyard survey.

Secondly, the data are not time series data collected on a representative orchard of each tree type. They are cross-sectional, representing a wide range of climates, soils, markets and, most importantly, levels of managerial skill. By itself, this fact is not necessarily a serious problem, for it shows the vast diversity of ability and practices of New York apple growers. It becomes important when taken together with the third problem, however, which is the fact that only one year of data was used, that representing the 1980 harvest season.

The fourth problem is that a fundamental econometric assumption is violated by the grouping of data within age categories. Grouping data leads to the variance of the error term in the classical linear regression model being heteroscedastic. This means that the estimator is less efficient than an

[4]Though it is recognized that this "stepwise" method of choosing a functional form is frowned upon by statisticians, it is also recognized that there are very few other ways to accomplish the goal of finding the "best" functional form when working with a hitherto unexplored data set where no theoretical basis for function form exists.

Figure 5. Form used for Organizing Yield Data by Rootstock and Age Category

Regional Code	County Code	Variety	Rootstock	Age 1-3	Age 4-6	Age 7-11	Age 12-21	Age 22+	Total Trees	Yield/ Tree	Total Yield
			Standard								
			M-2								
			M-7								
			M-9								
			M-26								
			MM-106								
			MM-111								
			Interstem 9/106								
			Interstem 9/111								
			Other								

estimator from ungrouped data. The problem can be solved by using a weighted regression technique, estimating the equation:

$$(5) \quad \sqrt{n_i}\ \bar{y}_i = \alpha \sqrt{n_i} + B \sqrt{n_i}\ \bar{x}_i \text{ (Maddala).}$$

Since there are other violations of the assumptions of the classical linear regression model present in this analysis (as is the case in most econometric work), it was decided that additional sophistication in the estimation of the required yield curves was not necessary.

Another problem rests in the choice of an age designation for the "22+" age category. It is an open-ended category, which makes it nearly meaningless econometrically. The analyst has considerable control over the height and general shape of estimated yield curves merely by choosing the age which represents the last category. It was initially assumed that using younger ages for the last category would move the peak of an estimated curve forward in time, and vice versa for older ages. This experiment was tried, but the most notable difference in the shape of the curve was to compress it, and make the maximum yield unrealistically high. Setting the last category at 30 years was based on the opinions of researchers, extension agents, and growers regarding the probable economic life of orchards. The 30 year age designation also gave the most plausible results in terms of the height and general shape of the estimated yield curves.

The three estimated yield equations are given in Table 5. A maximum was calculated and converted to bushels per acre for each estimated yield equation. In addition, a regression was run on the mean yields for each age category. R^2 was extremely high for all three regressions on the means, and all coefficients are significant at the five percent level. This could be interpreted as a reinforcement of the validity of choosing the linear-quadratic functional form, but it also shows the effect of removing the extreme variation in yield for each age category which is due to the use of cross-sectional data. Summary data for yield per tree are contained in Table 6 and the yield curves are in Figure 6.

The yields obtained by estimating functions from the available data were stated in bushels per tree. This being the case, the per acre yields are extremely sensitive to the choice of planting density for each planting system. The planting densities used (45 trees per acre for standard, 110 trees per acre for semi-dwarf, and 130 trees per acre for interstem) were chosen based on conversations with pomologists regarding probable field practices in the years represented by the data. The per acre yield curves for these planting densities are in Figure 7 with the resulting projected yields per acre in Table 7.

Since there is room for considerable variation in yields per acre as a result of the choice of planting density, the yields estimated in this analysis were compared with those estimated by Khera and Crowe. For standard trees, Khera and Crowe used a planting density of 58 trees per acre and obtained a maximum yield of 850 bushels per acre at 30 years of age. This figure is considerably higher than our maximum yields, for reasons which will be discussed later. For semi-dwarf trees, Khera and Crowe used a density of 155 trees per acre and obtained a maximum yield of 950 bushels per acre at age 23. This is extremely close to our results. For interstem and dwarf

Table 5. Estimated Yield Functions for Apples for Three Planting Systems Using all Observations and Means of Age Categories.

Planting System	B_0 a/	B_1 a/	B_2 a/	Trees/ Acre	Maximum Production Bu/Acre	Age at Maximum Production	R_2	Data Points Used in Estimation
Standard	-.0296	.854 (5.41)	-.0139 (-3.83)	45	591	30	.051	all
Semi-Dwarf	-.386	.720 (9.30)	-.0149 (-6.05)	110	914	24	.168	all
Interstem & Dwarf	.578	.795 (2.59)	-.0172 (-1.72)	130	1,269	23	.110	all
Standard	-.531	.922 (9.89)	-.0156 (-6.09)	45	589	30	.998	means only
Semi-Dwarf	-.473	.718 (5.53)	-.0145 (-4.05)	110	925	25	.988	means only
Interstem & Dwarf	-.265	.924 (3.08)	-.0211 (-2.55)	130	1,280	22	.941	means only

a/Functional Form: $Y = B_0 + B_1 X + B_2 X^2$ (t - ratios are in parentheses)
where Y = yield in bushels per tree
X = age

Table 6. Summary Data from Yield Functions by Age Categories and Planting System

Planting System	Age Category			
	4-6	7-11	12-21	22+
Age Used in Regression	5	9	17	30
Standard:				
No. of Observations	30	120	624	3042
Mean Yield per Tree	3.54	6.76	10.48	13.08
Standard Deviation	5.14	4.58	6.45	7.16
Semi-Dwarf:				
No. of Observations	226	412	315	46
Mean Yield per Tree	2.55	5.18	7.35	8.07
Standard Deviation	3.15	4.25	4.25	4.75
Interstem and Dwarf:				
No. of Observations	75	30	19	5
Mean Yield per Tree	4.30	5.50	9.81	8.42
Standard Deviation	5.46	5.46	6.08	2.70

Table 7. Projected Yields (Bushels per Acre) for Standard, Semi-Dwarf, and Interstem and Dwarf Planting Systems

Year	Tree Type		
	Standard	Semi-Dwarf	Interstem and Dwarf
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	60
5	0	120	150
6	60	250	400
7	110	374	615
8	240	432	689
9	269	486	759
10	297	538	824
11	323	586	885
12	348	630	941
13	372	672	993
14	395	710	1,041
15	417	745	1,084
16	437	777	1,122
17	456	805	1,156
18	474	830	1,186
19	490	852	1,211
20	506	871	1,232
21	520	886	1,248
22	533	898	1,259
23	544	912	1,267
24	554	907	1,269
25	563	914	1,268
26	571	913	1,261
27	578	909	1,251
28	583	901	1,236
29	587	890	1,216
30	590	876	1,192

Figure 6. Yield Curves for Standard, Semi-Dwarf and Interstem, and Dwarf Planting Systems, Bushels per Tree

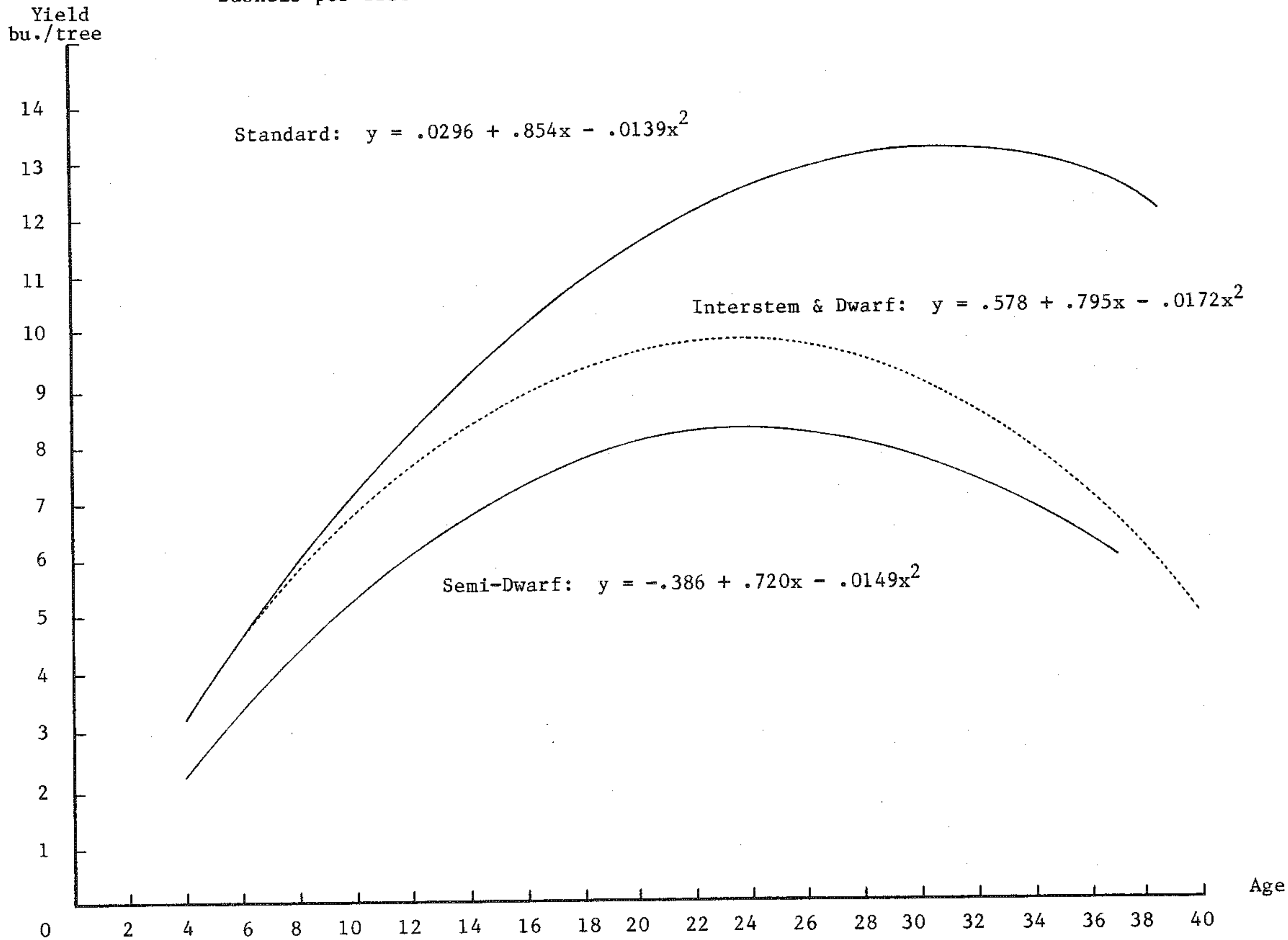


Figure 7. Yield Curves for Standard Semi-Dwarf and Interstem, and Dwarf Planting Systems, Bushels per Acre

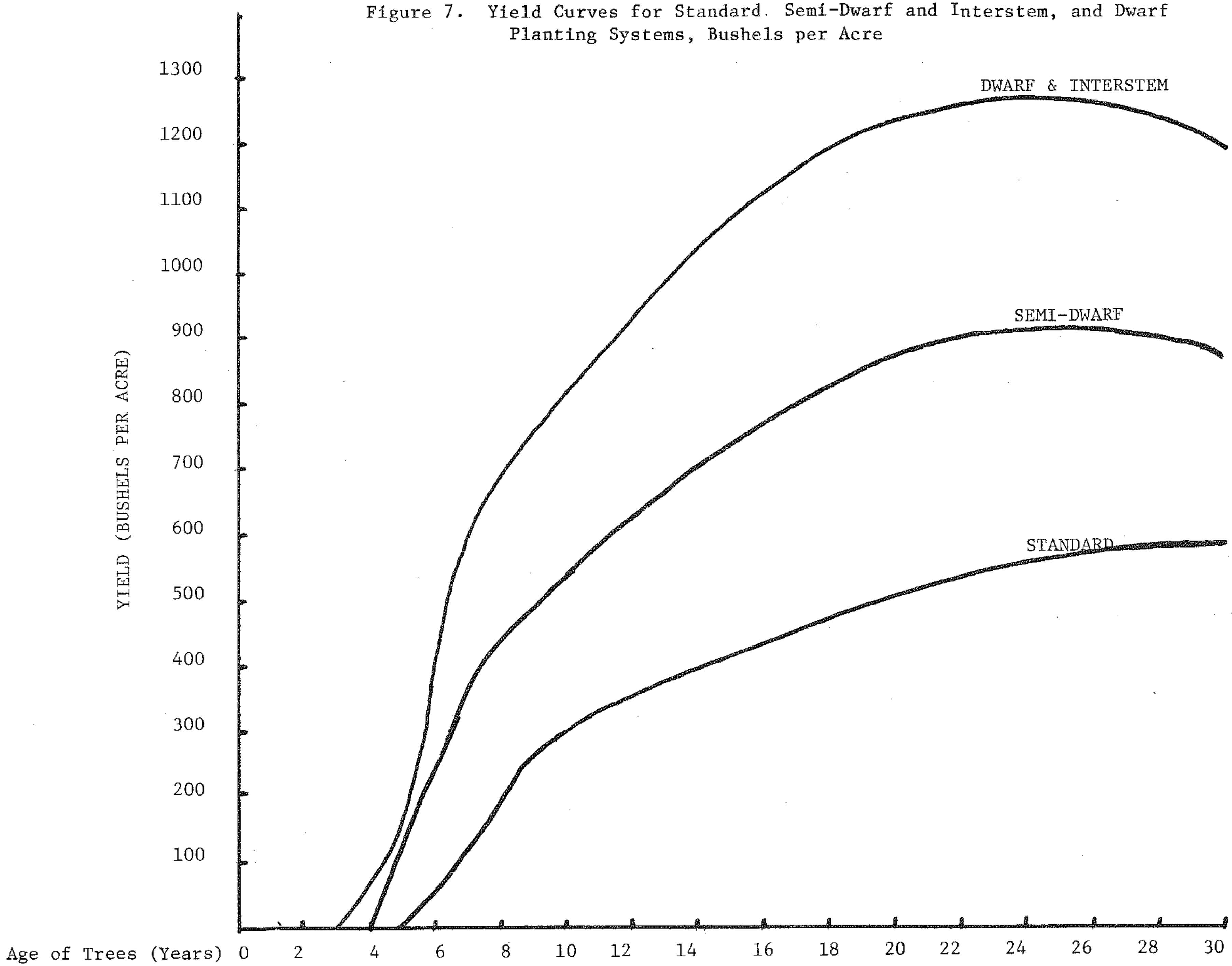


FIGURE 1. PROJECTED YIELDS, FOUR PLANTING SYSTEMS, NEW YORK, 1980.

trees, Khera and Crowe used a planting density of 340 trees per acre and achieved a maximum of 1,000 bushels per acre at age 20. They were not, however, as confident of this yield estimate as they were for their other estimates, primarily due to the small data base for higher density systems.

Khera and Crowe state that the yields quoted above are high yields that should be obtained under good management on good sites. Our data represent a cross section taken for the entire state of New York, and as such are reduced by the inclusion of some very marginal orchards and planting sites. Another fact concerning the data used in this report for standard trees is that a large proportion (80 percent) of the standard trees fall into the "22+" age category. This suggests that there are trees in the sample which may be 50 years old or older. The implication of inclusion of these older trees is lower production due to three factors:

1) The older trees have probably surpassed their peak production years and thus tend to pull the average down.

2) A larger proportion of the older trees were planted on marginal sites than is currently economical, partly from ignorance of the factors constituting a good planting site and partly because competition was not as keen 30 years ago and high production was not essential to survival. This tends to reduce the yields of the older trees.

3) There may be a reduction of yields on the older trees due to differences in managerial ability.

The foregoing reasons also relate to the choice of 30 years as the cutoff point in the economic life of an orchard that is used in this report. Even though the data show that a standard orchard has its yield peak at 30 years, after much consultation with growers, pomologists and agricultural economists, it was decided that 30 years would be the longest period of time that a grower would want to keep an orchard under current conditions.

The Dynamic Programming Model

The objective maximized by the dynamic programming model is the net present value of after-tax cash flow from the selected optimal replacement orchard planting system. This is accomplished via the Howard approach to dynamic programming introduced earlier (pp. 22-24, Figure 3).

The details of the Howard Approach are presented below:

1) Value Determination: For a chosen policy R_1, use $P_{ij}(K_1)$ and Q_{iK_1} to solve

$$(6) \quad V_i(R_1) = Q_{ik} + \sum_{j=0}^{N} P_{ij}(K_1)V_j(R_1), \quad (i=0, 1, \ldots, m)$$

for the unknown $V_i(R_1)$'s.

2) Policy Improvement: Using the current values of $V_i(R_1)$ find an alternative policy (R_2). For each state i, find K_2 that maximizes

$$(7) \quad Q_{iK_2} + \sum_{j=0}^{N} P_{ij}(K_2)V_j(R_1)$$

and set $d_i(R_2)$ = the maximizing value of K_2. A new policy, R_2, is defined. If policies R_1 and R_2 are not equivalent, solve 6 again using R_2. Continue iterations until two successive policies are found to be identical.

Where:

i = the current state of the system,

j = the new state of the system in the next observed time period,

n = the current time period,

R = the policy followed,

$d_i(R)$ = k = the decision made in state i when following policy R,

Q_{iK} = the expected return in state i obtained from following policy R,

P_{ij} = the transitional probability, or the probability that the system is now in state i and that decision k is made,

B = the discount rate,

and $V_iN(R)$ = the expected long-run total discounted after-tax cash flow for the system starting in state i and continuing indefinitely.

The primary input to the dynamic programming model is the after-tax cash flow (ATCF) from the simulation model. ATCF becomes Q in the equations above. Other inputs are entered by the operator and include the user's tax bracket, current or expected, the choice of cost recovery period, the choice of a real discount rate, the tree type of the original orchard, and the age of the original orchard.

The dynamic programming model is initialized by defining five policies, (Figure 8):

1. keep the current orchard,
2. replace with standard trees,
3. replace with semi-dwarf trees,
4. replace with interstem trees,
5. replace with dwarf trees,

and establishing the 120 stages necessary for solution. An initial estimate of V in equation 6 is made. This initial V is designated QT by the dynamic programming model and is defined in such a way that the optimal alternative in each stage is to keep the current planting system, unless it is 30 years old, at which age replacement is forced.

The Value subroutine is entered next. Value finds the maximum QT at each stage and creates a vector which shows the alternative associated with maximum QT at each stage. This vector is defined as MAXALT. Associated with the alternatives listed in MAXALT is a vector of immediate (one year) after-tax cash flows. Elements of this vector, defined as SELQ, are merely the Q's defined earlier. The next step is to find the new vector of V's given the matrix of transitional probabilities and the vector SELQ.

Figure 8. Diagramatic Representation of The Dynamic Programming Replacement Model.

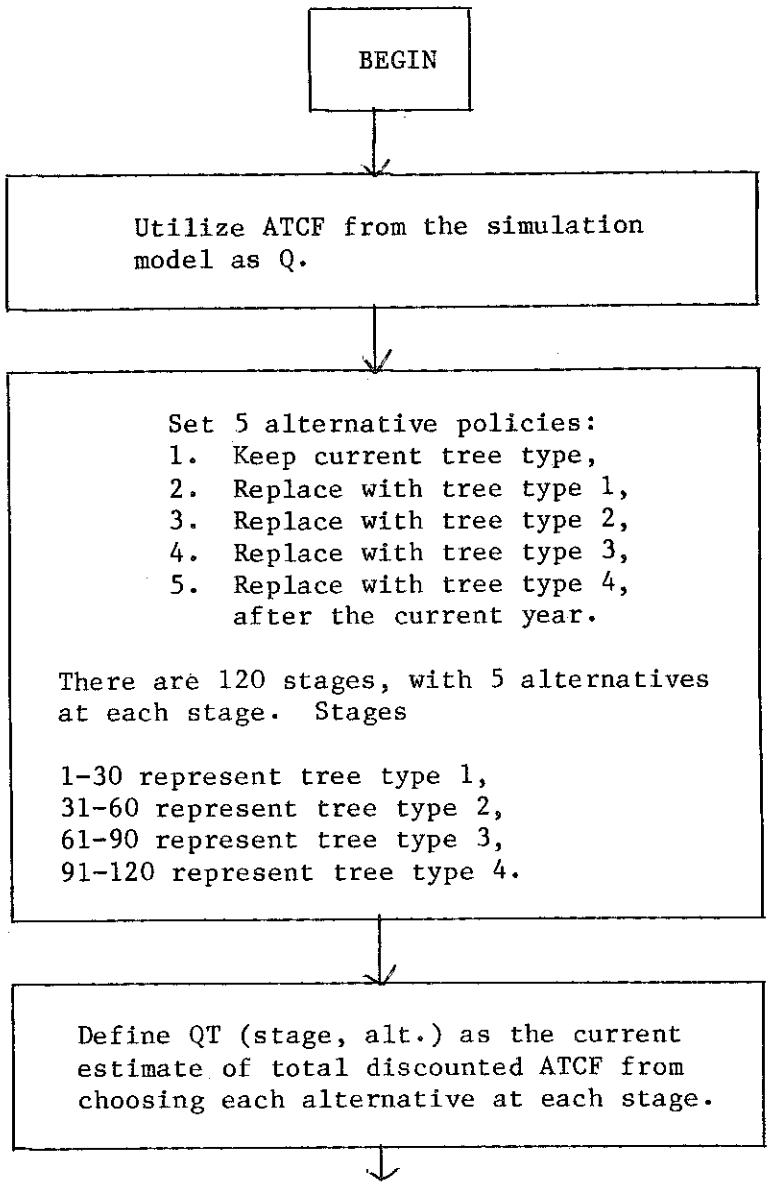


Figure 8 continued.

↓

Initial QT (model startup)

QT(1, stage) = Q(tree, J, J = age)
QT(2, stage) = Q(1, 1)
QT(3, stage) = Q(2, 1)
QT(4, stage) = Q(3, 1)
QT(5, stage) = Q(4, 1)

QT for "keep" alternative is ATCF for current tree type of age J

QT for "replace" alternative is ATCF for the first year of each possible new orchard.

↓

A→

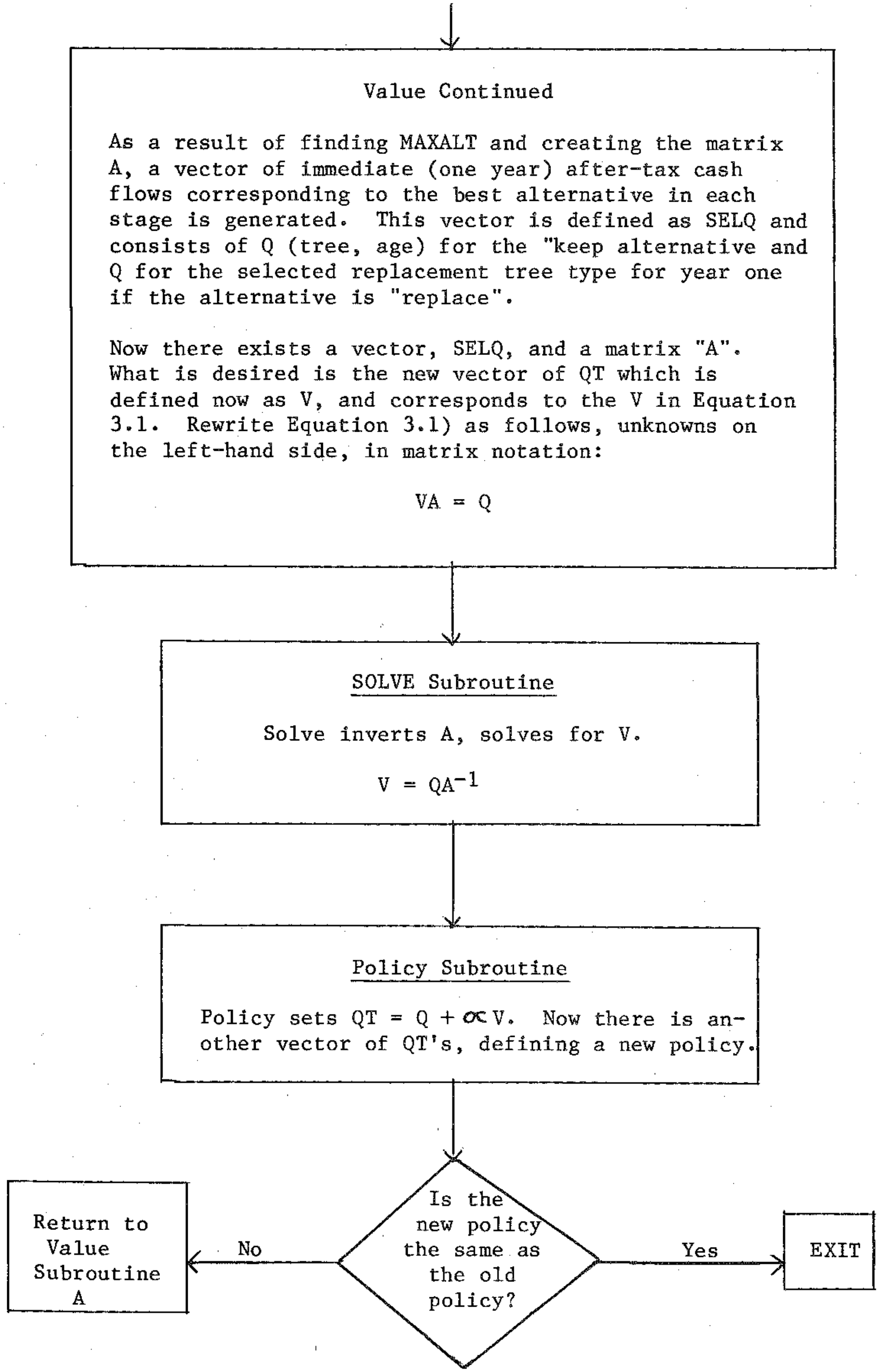
<u>Value Subroutine</u>

Value finds the maximum QT at each stage, and selects the alternative corresponding to maximum QT. Then a vector containing the best alternative for each stage is created and called MAXALT.

Value now creates the "A" matrix of coefficients of the net discounted after-tax cash flow from following the policy in MAXALT. Elements of the "A" matrix are determined by examining whether the best alternative at each stage is "keep" or "replace" and by noting whether it is possible to move from one state to the next. "A" consists, then, of elements which are either 1, 0, or $-\alpha$, where α is the real discount rate.

↓

Figure 8 continued.



The matrix of transitional probabilities for this problem would consist of only zero and one element. Given a state, and a decision (policy alternative), there are only a few possible events which can occur. This simplifies the development of the matrix of transitional probabilities to the strategic placement of ones. The matrix "A" has another characteristic, however. If equation 6 were rewritten with the probabilities substituted and unknowns on the left-hand side, it would be:

$$V_i - \alpha V_j = Q_{iK}.$$

α is the real discount rate; this equation is combined with the matrix of transitional probabilities to form the matrix "A". Value performs this operation. The "A" matrix appears in Figure 9.

At the end of the Value subroutine, a matrix equation of the form VA = Q is obtained. V is unknown, and the Solve subroutine is entered at this point. Solve inverts the A matrix, premultiplies it by the Q vector, and thus solves for V; $V = QA^{-1}$. The program then enters the subroutine designated Policy, and a vector of QT's is defined for another iteration in Value. See Figure 10 for a short flow chart of the entire dynamic programming model. The optimal solution is reached when two MAXALT vectors are obtained which are identical.

Output from the Replacement Model

The dynamic programming model prints a statement telling when to replace, and with which planting system, and shows all of the operator input decisions (Figure 11). There is also the option of printing out the 1 x 120 vector of optimal alternatives (MAXALT). The MAXALT optimal vector in Figure 11 can be interpreted as follows: For all of the years in the economic life of the standard system (stages 1-30) replacement with interstem trees is optimal. The NPV of doing so is $33,636. For semi-dwarf plantings between the ages of one and eight, replacement with interstem trees is optimal, and the NPV is $33,636. For semi-dwarf trees between the ages of nine and 29, the optimal alternative is to keep the trees, and the NPV for this alternative ranges between $33,951 and $36,920. Replacement occurs at age 30 for the semi-dwarf system, with interstem trees. For interstem trees the best alternative is to keep them unless they are age 30, at which age they should be replaced with interstem trees. The NPV ranges from $34,979 to $51,066. Dwarf trees should also be kept unless they are 30 years old, with an NPV of $35,572 to $59,415. Dwarfs should be replaced at age 30 with interstem trees.

The simulation model prints out three different forms of information pertinent to an individual grower's operation. Upon request, a budget may be obtained, showing costs of production by component, including hours required for each operation, labor cost, machinery cost, materials cost, and total cost per acre, for any year in the 30 year economic life of each of the four planting systems (Tables 8, 9, 10, and 11). The operator also has the option of having the total costs of production, by operation, for 30 years, printed out for each system (Table 12). Finally, a schedule showing the components of after tax cash flow as computed in the model, for 30 years for each system can be obtained (Table 13).

Figure 9. The "A" Matrix of Coefficients used in the Solve Subroutine of the Dynamic Programming Replacement Model

state \ state	1	2	3	4	5	···	30	31	···	60	61	···	90	91	···	120
1	1	$-\alpha$	0	0	0	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
2	$-\alpha$	1	$-\alpha$	0	0	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
3	$-\alpha$	0	1	$-\alpha$	0	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
4	$-\alpha$	0	0	1	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
5	$-\alpha$	0	0	0	1	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮		⋮	⋮		⋮	⋮		⋮
30	$-\alpha$	0	0	0	0	···	1	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	0
31	$-\alpha$	0	0	0	0	···	0	1	···	0	$-\alpha$	···	0	$-\alpha$	···	0
⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮		⋮	⋮		⋮	⋮		⋮
60	$-\alpha$	0	0	0	0	···	0	$-\alpha$	···	1	$-\alpha$	···	0	$-\alpha$	···	0
61	$-\alpha$	0	0	0	0	···	0	$-\alpha$	···	0	1	···	0	$-\alpha$	···	0
⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮		⋮	⋮		⋮	⋮		⋮
90	$-\alpha$	0	0	0	0	···	0	$-\alpha$	···	0	$-\alpha$	···	1	$-\alpha$	···	0
91	$-\alpha$	0	0	0	0	···	0	$-\alpha$	···	0	$-\alpha$	···	0	1	···	0
⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮		⋮	⋮		⋮	⋮		⋮
120	$-\alpha$	0	0	0	0	···	0	$-\alpha$	···	0	$-\alpha$	···	0	$-\alpha$	···	

Figure 10. Summary Flow Chart of The Dynamic Programming Replacement Model

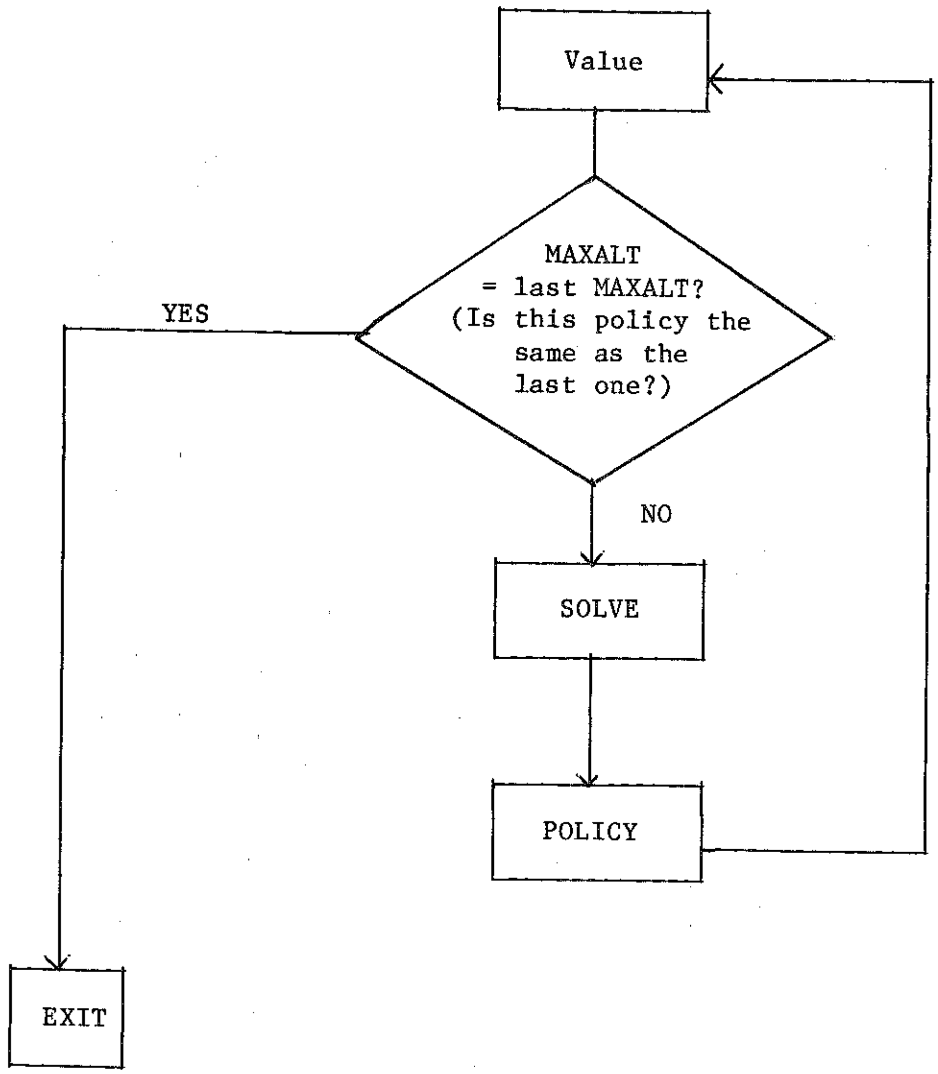


Figure 11. Sample Output from the Replacement Model

```
OUTPUT SPOOLING BEGINS


                         PLEASE ENTER THE NAME OF THE DATA FILE
                          CONTAINING THE ORCHARD DATA YOU WANT
                            USED BY THE OPTIMIZATION MODEL.


CAT


OPTIMAL ORCHARD REPLACEMENT PROGRAM

  PLEASE ENTER A NAME FOR THIS RUN

COPY RUN 1
 ENTER TAX BRACKET AS A DECIMAL..  (E.G. 0.42)
?
.25
 ENTER COST RECOVERY SCHEDULE FOR ORCHARD.
    FOR 5 YEAR COST RECOVERY ENTER 5
    FOR 12 YR. COST RECOVERY ENTER 12
    FOR 25 YR. COST RECOVERY ENTER 25
?
5
ENTER INTEREST RATE (%)
?
3
ENTER TREE TYPE OF ORIGINAL ORCHARD
? 00077
1
ENTER AGE OF CURRENT ORCHARD
?
25


REPLACE WITH INTERSTEM TREES     1 YEARS FROM NOW

CONVERGENCE IN     5 ITERATIONS


     DO YOU WANT AN OUTPUT DUMP FROM OPT?

YES
```

Figure 11 continued

RESULT DUMP FROM ORCHARD OPTIMIZATION PROGRAM
RUN NAME: COPY RUN 1

INTEREST RATE = 3.0000
TAX BRACKET = 0.2500
COST RECOVERY PERIOD = 5 YEARS

STATE,	OPTIMAL ALTERNATIVE,	"V"	STATE,	OPTIMAL ALTERNATIVE,	"V"
1	4	33636.11720000	2	4	33636.11720000
3	4	33636.11720000	4	4	33636.11720000
5	4	33636.11720000	6	4	33636.11720000
7	4	33636.11720000	8	4	33636.11720000
9	4	33636.11720000	10	4	33636.11720000
11	4	33636.11720000	12	4	33636.11720000
13	4	33636.11720000	14	4	33636.11720000
15	4	33636.11720000	16	4	33636.11720000
17	4	33636.11720000	18	4	33636.11720000
19	4	33636.11720000	20	4	33636.11720000
21	4	33636.11720000	22	4	33636.11720000
23	4	33636.11720000	24	4	33636.11720000
25	4	33636.11720000	26	4	33636.11720000
27	4	33636.11720000	28	4	33636.11720000
29	4	33636.11720000	30	4	33636.11720000
31	4	33636.11720000	32	4	33636.11720000
33	4	33636.11720000	34	4	33636.11720000
35	4	33636.11720000	36	4	33636.11720000
37	4	33636.11720000	38	4	33636.11720000
39	1	34240.08590000	40	1	35184.00780000
41	1	35680.34370000	42	1	36094.62110000
43	1	36411.50780000	44	1	36655.55860000
45	1	36811.71480000	46	1	36904.81250000
47	1	36920.08590000	48	1	36882.67190000
49	1	36778.11720000	50	1	36631.88670000
51	1	36429.85550000	52	1	36197.82030000
53	1	35922.01560000	54	1	35628.58980000
55	1	35304.15230000	56	1	34975.23830000
57	1	34628.84770000	58	1	34291.93360000
59	1	33951.89450000	60	4	33636.11720000
61	1	37297.85940000	62	1	41069.45310000
63	1	42550.31250000	64	1	44116.42970000
65	1	45745.14450000	66	1	47615.67970000
67	1	48924.60940000	68	1	49885.44140000
69	1	50676.89060000	70	1	50955.22270000
71	1	51066.21090000	72	1	51038.52340000
73	1	50856.82810000	74	1	50550.18360000
75	1	50103.68360000	76	1	49546.81250000
77	1	48865.08980000	78	1	48088.45310000
79	1	47202.88670000	80	1	46238.80470000
81	1	45182.68750000	82	1	44065.45700000
83	1	42874.11720000	84	1	41640.11330000
85	1	40351.01170000	86	1	39038.83590000
87	1	37691.72270000	88	1	36342.30470000
89	1	34979.34770000	90	4	33636.13280000
91	1	39984.86720000	92	1	46831.55470000
93	1	48517.90230000	94	1	50297.05470000
95	1	52391.50780000	96	1	54951.56640000
97	1	56839.94530000	98	1	58155.19140000
99	1	59278.47660000	100	1	59415.59370000
101	1	59352.05860000	102	1	59115.33980000
103	1	58693.39450000	104	1	58114.16410000
105	1	57366.08980000	106	1	56477.59770000
107	1	55437.63670000	108	1	54275.14450000
109	1	52979.60550000	110	1	51580.52730000
111	1	50067.95700000	112	1	48471.98440000
113	1	46783.26950000	114	1	45032.51950000
115	1	43211.03520000	116	1	41350.17970000
117	1	39441.92190000	118	1	37518.34770000
119	1	35572.14060000	120	4	33636.13280000

Table 8. Variable Costs of Producing Apples, Standard Planting System, 25 Year Old Orchard

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
(PER ACRE FOR ONE YEAR)
STANDARD TREES 25 YEAR OLD ORCHARD

OPERATION	HOURS/ACRE	LABOR COST	MACHINERY COSTS	MATERIALS COST	TOTAL COST
CULTURAL COSTS					
PRUNING	24.00	110.40	5.00	0.00	115.40
MOWING	4.00	22.08	20.16	0.00	42.24
HERBICIDE 1	1.60	8.83	5.76	11.52	26.11
HERBICIDE 2	0.80	4.42	2.88	5.76	13.06
INSECTICIDE	2.64	14.57	29.83	47.20	91.60
FUNGICIDE	3.63	20.04	41.02	61.60	122.66
THINNING	0.33	1.82	3.73	10.00	15.55
ALAR	0.33	1.82	3.73	31.00	36.55
ETHREL	0.33	1.82	3.73	5.50	11.05
FERTILIZER	0.50	2.76	1.77	55.00	59.53
BEE HIVES	0.00	0.00	0.00	8.25	8.25
MOUSEBAIT	0.30	1.38	0.00	3.30	4.68
IRRIGATION	1.00	0.00	125.00	50.00	175.00
N.A.A. SPRAY	0.20	0.92	0.00	18.00	18.92
MISCELLANEOUS					25.00
TOTAL CULTURAL COSTS					765.61
HARVEST COSTS					
TOTAL HARVEST COST, PER BUSHEL					1.65

Table 9. Variable Costs of Producing Apples, Semi-Dwarf Planting System, 25 Year Old Orchard

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
(PER ACRE FOR ONE YEAR)
SEMI-DWARF TREES 25 YEAR OLD ORCHARD

OPERATION	HOURS/ACRE	LABOR COST	MACHINERY COSTS	MATERIALS COST	TOTAL COST
CULTURAL COSTS					
PRUNING	44.00	202.40	5.00	0.00	207.40
MOWING	4.00	22.08	20.16	0.00	42.24
HERBICIDE 1	1.60	8.83	5.76	20.00	34.59
HERBICIDE 2	0.80	4.42	2.88	5.76	13.06
INSECTICIDE	2.64	14.57	24.82	47.20	86.59
FUNGICIDE	3.63	20.04	34.12	61.60	115.76
THINNING	0.33	1.82	3.10	10.00	14.92
ALAR	0.33	1.82	3.10	31.00	35.92
ETHREL	0.33	1.82	3.10	5.50	10.42
FERTILIZER	0.50	2.76	1.77	55.00	59.53
BEE HIVES	0.00	0.00	0.00	8.25	8.25
MOUSEBAIT	0.30	1.38	0.00	3.30	4.68
IRRIGATION	1.00	0.00	125.00	50.00	175.00
N.A.A. SPRAY	0.25	1.15	0.00	18.00	19.15
MISCELLANEOUS					20.00
TOTAL CULTURAL COSTS					847.52
HARVEST COSTS					
TOTAL HARVEST COST, PER BUSHEL					1.55

Table 10. Variable Costs of Producing Apples, Interstem Planting System, 25 Year Old Orchard

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
(PER ACRE FOR ONE YEAR)
INTERSTEM TREES 25 YEAR OLD ORCHARD

OPERATION	HOURS/ACRE	LABOR COST	MACHINERY COSTS	MATERIALS COST	TOTAL COST
CULTURAL COSTS					
PRUNING	44.00	202.40	5.00	0.00	207.40
MOWING	4.00	22.08	20.16	0.00	42.24
HERBICIDE 1	1.92	10.60	6.91	20.00	37.51
HERBICIDE 2	0.96	5.30	3.46	5.76	14.52
INSECTICIDE	3.17	17.49	29.78	47.20	94.47
FUNGICIDE	4.36	24.05	40.95	61.60	126.59
THINNING	0.40	2.19	3.72	10.00	15.91
ALAR	0.40	2.19	3.72	31.00	36.91
ETHREL	0.40	2.19	3.72	5.50	11.41
FERTILIZER	0.50	2.76	1.77	55.00	59.53
BEE HIVES	0.00	0.00	0.00	8.25	8.25
MOUSEBAIT	0.30	1.38	0.00	3.30	4.68
IRRIGATION	1.00	0.00	125.00	50.00	175.00
N.A.A. SPRAY	0.25	1.15	0.00	18.00	19.15
MISCELLANEOUS					20.00
TOTAL CULTURAL COSTS					873.56
HARVEST COSTS					
TOTAL HARVEST COST, PER BUSHEL					1.45

Table 11. Variable Costs of Producing Apples, Dwarf Planting System, 25 Year Old Orchard

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
(PER ACRE FOR ONE YEAR)
DWARF TREES 25 YEAR OLD ORCHARD

OPERATION	HOURS/ACRE	LABOR COST	MACHINERY COSTS	MATERIALS COST	TOTAL COST
CULTURAL COSTS					
PRUNING	23.00	105.80	5.00	0.00	110.80
MOWING	4.00	22.08	20.16	0.00	42.24
HERBICIDE 1	1.60	8.83	5.76	20.00	34.59
HERBICIDE 2	0.80	4.42	2.88	5.76	13.06
INSECTICIDE	4.40	24.29	40.26	43.60	108.15
FUNGICIDE	6.05	33.40	55.36	57.75	146.50
THINNING	0.55	3.04	5.03	10.00	18.07
ALAR	0.55	3.04	5.03	31.00	39.07
ETHREL	0.55	3.04	5.03	5.50	13.57
FERTILIZER	0.50	2.76	1.77	55.00	59.53
BEE HIVES	0.00	0.00	0.00	8.25	8.25
MOUSEBAIT	0.30	1.38	0.00	3.30	4.68
IRRIGATION	1.00	0.00	125.00	50.00	175.00
N.A.A. SPRAY	0.30	1.38	0.00	18.00	19.38
MISCELLANEOUS					18.00
TOTAL CULTURAL COSTS					810.89
HARVEST COSTS					
TOTAL HARVEST COST, PER BUSHEL					1.30

Table 12 Variable Costs of Production for 30 Years, By Planting System

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
STANDARD TREES

OPERATION	YEAR 1	2	3	4	5	6	7	8	9	10
PRUNING	5.00	23.40	23.40	32.60	41.80	51.00	115.40	115.40	115.40	115.40
MOWING	8.45	16.90	25.34	25.34	33.79	42.24	42.24	42.24	42.24	42.24
HERB. 1	0.00	6.53	6.53	13.06	26.11	13.06	26.11	13.06	26.11	13.06
HERB. 2	0.00	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	5.90	5.90	11.45	22.90	22.90	68.70	91.60	91.60	91.60	91.60
FUNGIC.	11.15	11.15	22.30	22.30	89.20	122.66	122.66	122.66	122.66	122.66
THINNING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.55	15.55	15.55
ALAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.55	36.55	36.55
ETHREL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.05	11.05	11.05
FERT.	0.00	32.03	45.78	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	0.00	0.00	0.00	0.00	0.00	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	0.00	0.00	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92
MISC.	10.00	10.00	10.00	15.00	20.00	25.00	25.00	25.00	25.00	25.00
TOTAL	220.18	298.65	356.46	402.39	505.00	602.10	702.45	752.55	765.61	752.55

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
STANDARD TREES

OPERATION	YEAR 11	12	13	14	15	16	17	18	19	20
PRUNING	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	26.11	13.06	26.11	13.06	26.11	13.06	26.11	13.06	26.11	13.06
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60
FUNGIC.	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66
THINNING	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55
ALAR	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55
ETHREL	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92
MISC.	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
TOTAL	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55

Table 12 continued

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
STANDARD TREES

OPERATION	YEAR 21	22	23	24	25	26	27	28	29	30
PRUNING	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40	115.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	26.11	13.06	26.11	13.06	26.11	13.06	26.11	13.06	26.11	13.06
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60	91.60
FUNGIC.	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66	122.66
THINNING	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55	15.55
ALAR	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55
ETHREL	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92
MISC.	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
TOTAL	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
SEMI-DWARF TREES

OPERATION	YEAR 1	2	3	4	5	6	7	8	9	10
PRUNING	5.00	38.35	38.35	55.60	71.70	87.80	207.40	207.40	207.40	207.40
MOWING	8.45	16.90	25.34	25.34	33.79	42.24	42.24	42.24	42.24	42.24
HERB. 1	0.00	8.65	8.65	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	0.00	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	5.90	10.82	10.82	21.65	86.59	86.59	86.59	86.59	86.59	86.59
FUNGIC.	10.52	10.52	21.05	21.05	115.76	115.76	115.76	115.76	115.76	115.76
THINNING	0.00	0.00	0.00	0.00	0.00	0.00	14.92	14.92	14.92	14.92
ALAR	0.00	0.00	0.00	0.00	0.00	0.00	35.92	35.92	35.92	35.92
ETHREL	0.00	0.00	0.00	0.00	0.00	0.00	10.42	10.42	10.42	10.42
FERT.	0.00	32.03	45.78	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	0.00	0.00	0.00	0.00	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	0.00	0.00	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	10.00	10.00	10.00	15.00	15.00	20.00	20.00	20.00	20.00	20.00
TOTAL	219.55	320.01	371.88	427.35	637.10	649.35	847.52	830.22	847.52	830.22

Table 12 continued

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
SEMI-DWARF TREES

OPERATION	11	12	13	YEAR 14	15	16	17	18	19	20
PRUNING	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59
FUNGIC.	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76
THINNING	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92
ALAR	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92
ETHREL	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
TOTAL	847.52	830.22	847.52	830.22	847.52	830.22	847.52	830.22	847.52	830.22

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
SEMI-DWARF TREES

OPERATION	21	22	23	YEAR 24	25	26	27	28	29	30
PRUNING	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59	86.59
FUNGIC.	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76	115.76
THINNING	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92	14.92
ALAR	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92	35.92
ETHREL	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
TOTAL	847.52	830.22	847.52	830.22	847.52	830.22	847.52	830.22	847.52	830.22

Table 12 continued

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
INTERSTEM TREES

OPERATION	YEAR 1	2	3	4	5	6	7	8	9	10
PRUNING	5.00	38.35	38.35	55.60	71.70	87.80	207.40	207.40	207.40	207.40
MOWING	8.45	16.90	25.34	25.34	33.79	42.24	42.24	42.24	42.24	42.24
HERB. 1	0.00	9.38	9.38	18.76	37.51	18.76	37.51	18.76	37.51	18.76
HERB. 2	0.00	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52
INSECT.	5.90	11.81	11.81	23.62	94.47	94.47	94.47	94.47	94.47	94.47
FUNGIC.	11.51	11.51	23.02	23.02	126.59	126.59	126.59	126.59	126.59	126.59
THINNING	0.00	0.00	0.00	0.00	0.00	0.00	15.91	15.91	15.91	15.91
ALAR	0.00	0.00	0.00	0.00	0.00	0.00	36.91	36.91	36.91	36.91
ETHREL	0.00	0.00	0.00	0.00	0.00	0.00	11.41	11.41	11.41	11.41
FERT.	0.00	32.03	45.78	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	0.00	0.00	0.00	0.00	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	0.00	0.00	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	10.00	10.00	10.00	15.00	15.00	20.00	20.00	20.00	20.00	20.00
TOTAL	220.54	324.17	377.03	434.21	660.19	670.98	873.56	854.81	873.56	854.81

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
INTERSTEM TREES

OPERATION	YEAR 11	12	13	14	15	16	17	18	19	20
PRUNING	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	37.51	18.76	37.51	18.76	37.51	18.76	37.51	18.76	37.51	18.76
HERB. 2	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52
INSECT.	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47
FUNGIC.	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59
THINNING	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91
ALAR	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91
ETHREL	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
TOTAL	873.56	854.81	873.56	854.81	873.56	854.81	873.56	854.81	873.56	854.81

Table 12 continued

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
INTERSTEM TREES

OPERATION	YEAR 21	22	23	24	25	26	27	28	29	30
PRUNING	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40	207.40
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	37.51	18.76	37.51	18.76	37.51	18.76	37.51	18.76	37.51	18.76
HERB. 2	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52	14.52
INSECT.	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47	94.47
FUNGIC.	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59	126.59
THINNING	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91	15.91
ALAR	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91	36.91
ETHREL	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41	11.41
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
MISC.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
TOTAL	873.56	854.81	873.56	854.81	873.56	854.81	873.56	854.81	873.56	854.81

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
DWARF TREES

OPERATION	YEAR 1	2	3	4	5	6	7	8	9	10
PRUNING	5.00	74.00	74.00	110.80	110.80	110.80	110.80	110.80	110.80	110.80
MOWING	8.45	16.90	25.34	25.34	33.79	42.24	42.24	42.24	42.24	42.24
HERB. 1	0.00	8.65	8.65	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	0.00	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	5.45	5.45	13.52	81.11	108.15	108.15	108.15	108.15	108.15	108.15
FUNGIC.	13.32	26.64	26.64	106.55	146.50	146.50	146.50	146.50	146.50	146.50
THINNING	0.00	0.00	0.00	0.00	18.07	18.07	18.07	18.07	18.07	18.07
ALAR	0.00	0.00	0.00	0.00	39.07	39.07	39.07	39.07	39.07	39.07
ETHREL	0.00	0.00	0.00	0.00	13.57	13.57	13.57	13.57	13.57	13.57
FERT.	0.00	32.03	45.78	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	0.00	0.00	0.00	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	0.00	0.00	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38
MISC.	5.00	10.00	15.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
TOTAL	216.90	366.40	421.05	639.00	802.44	793.59	810.89	793.59	810.89	793.59

Table 12 continued

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
DWARF TREES

OPERATION	YEAR 11	12	13	14	15	16	17	18	19	20
PRUNING	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15
FUNGIC.	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50
THINNING	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07
ALAR	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07
ETHREL	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38
MISC.	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
TOTAL	810.89	793.59	810.89	793.59	810.89	793.59	810.89	793.59	810.89	793.59

NEW YORK STATE
VARIABLE COSTS OF PRODUCTION OF APPLES
DWARF TREES

OPERATION	YEAR 21	22	23	24	25	26	27	28	29	30
PRUNING	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80	110.80
MOWING	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24	42.24
HERB. 1	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30	34.59	17.30
HERB. 2	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06	13.06
INSECT.	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15	108.15
FUNGIC.	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50	146.50
THINNING	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07	18.07
ALAR	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07	39.07
ETHREL	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57
FERT.	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53	59.53
BEE HIVE	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
MSEBAIT	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
IRRIG.	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
NAA SPR.	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.38
MISC.	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
TOTAL	810.89	793.59	810.89	793.59	810.89	793.59	810.89	793.59	810.89	793.59

Table 13 After-Tax Cash Flow, By Planting System, for 30 Years

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
STANDARD TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 1	2	3	4	5	6	7	8	9	10
GROSS REVENUE	0.0	0.0	0.0	0.0	0.0	224.16	410.96	895.49	1004.01	1107.86
HARVEST COSTS	0.0	0.0	0.0	0.0	0.0	99.00	181.50	395.49	443.42	489.28
OPERATING COSTS	220.18	298.65	356.46	402.39	505.00	602.10	702.45	752.55	765.61	752.55
OPERATING INCOME	-220.18	-298.65	-356.46	-402.39	-505.00	-476.94	-472.99	-252.55	-205.01	-133.97
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	343.00	343.00	343.00	343.00	343.00
TAXABLE INCOME	-220.18	-298.65	-356.46	-402.39	-505.00	-819.94	-815.99	-595.55	-548.01	-476.97
TAX	-55.04	-74.66	-89.12	-100.60	-126.25	-204.98	-204.00	-148.89	-137.00	-119.24
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	171.50	0.0	0.0	0.0	0.0
NET TAX PAID	-55.04	-74.66	-89.12	-100.60	-126.25	-376.48	-204.00	-148.89	-137.00	-119.24
CAPITALIZED INV.	1715.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	-1880.13	-223.98	-267.35	-301.79	-378.75	-443.45	-612.00	-446.66	-411.01	-357.73

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
STANDARD TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 11	12	13	14	15	16	17	18	19	20
GROSS REVENUE	1207.03	1301.53	1391.36	1476.51	1556.99	1632.80	1703.93	1770.39	1832.17	1889.28
HARVEST COSTS	533.08	574.82	614.49	652.10	687.64	721.12	752.54	781.89	809.18	834.40
OPERATING COSTS	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55
OPERATING INCOME	-91.66	-25.84	11.26	71.86	103.74	159.12	185.78	235.95	257.39	302.33
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	-91.66	-25.84	11.26	71.86	103.74	159.12	185.78	235.95	257.39	302.33
TAX	-22.91	-6.46	2.82	17.97	25.94	39.78	46.45	58.99	64.35	75.58
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	-22.91	-6.46	2.82	17.97	25.94	39.78	46.45	58.99	64.35	75.58
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	-68.74	-19.38	8.45	53.90	77.81	119.34	139.34	176.96	193.04	226.75

Table 13 continued

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
STANDARD TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 21	22	23	24	25	26	27	28	29	30
GROSS REVENUE	1941.71	1989.48	2032.57	2070.98	2104.72	2133.79	2158.19	2177.91	2192.95	2203.32
HARVEST COSTS	857.56	878.65	897.68	914.65	929.55	942.39	953.16	961.87	968.51	973.10
OPERATING COSTS	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55	765.61	752.55
OPERATING INCOME	318.55	358.28	369.28	403.79	409.57	438.85	439.42	463.49	458.83	477.68
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	318.55	358.28	369.28	403.79	409.57	438.85	439.42	463.49	458.83	477.68
TAX	79.64	89.57	92.32	100.95	102.39	109.71	109.85	115.87	114.71	119.42
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	C.0	0.0	0.0
NET TAX PAID	79.64	89.57	92.32	100.95	102.39	109.71	109.85	115.87	114.71	119.42
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	238.91	268.71	276.96	302.84	307.18	329.14	329.56	347.61	344.12	358.26

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
SEMI-DWF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 1	2	3	4	5	6	7	8	9	10
GROSS REVENUE	0.0	0.0	0.0	0.0	531.96	1108.25	1656.77	1913.41	2155.52	2383.09
HARVEST COSTS	0.0	0.0	0.0	0.0	186.00	387.50	579.29	669.02	753.68	833.25
OPERATING COSTS	219.55	317.89	369.76	423.11	628.62	645.13	839.04	825.98	839.04	825.98
OPERATING INCOME	-219.55	-317.89	-369.76	-423.11	-282.66	75.63	238.44	418.40	562.80	723.86
COST RECOVERY	0.0	0.0	0.0	0.0	455.00	455.00	455.00	455.00	455.00	0.0
TAXABLE INCOME	-219.55	-317.89	-369.76	-423.11	-737.66	-379.37	-216.56	-36.60	107.80	723.86
TAX	-54.89	-79.47	-92.44	-105.78	-184.42	-94.84	-54.14	-9.15	26.95	180.96
INVEST. CREDIT	0.0	0.0	0.0	0.0	227.50	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	-54.89	-79.47	-92.44	-105.78	-411.92	-94.84	-54.14	-9.15	26.95	180.96
CAPITALIZED INV.	2275.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	-2439.66	-238.42	-277.32	-317.34	-325.75	-284.52	-162.42	-27.45	80.85	542.89

Table 13 continued

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
SEMI-DWF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 11	12	13	14	15	16	17	18	19	20
GROSS REVENUE	2596.14	2794.65	2978.54	3148.08	3303.00	3443.39	3569.25	3680.58	3777.37	3859.63
HARVEST COSTS	907.74	977.15	1041.48	1100.73	1154.90	1203.99	1247.99	1286.92	1320.76	1349.52
OPERATING COSTS	839.04	825.98	839.04	825.98	839.04	825.98	839.04	825.98	839.04	825.98
OPERATING INCOME	849.36	991.52	1098.11	1221.37	1399.06	1413.42	1482.22	1567.67	1617.57	1684.12
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	849.36	991.52	1098.11	1221.37	1309.06	1413.42	1482.22	1567.67	1617.57	1684.12
TAX	212.34	247.88	274.53	305.34	327.26	353.35	370.55	391.92	404.39	421.03
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	212.34	247.88	274.53	305.34	327.26	353.35	370.55	391.92	404.39	421.03
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	637.02	743.64	823.59	916.02	981.80	1060.06	1111.66	1175.76	1213.17	1263.09

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
SEMI-DWF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 21	22	23	24	25	26	27	28	29	30
GROSS REVENUE	3927.36	3980.56	4019.23	4043.36	4052.98	4048.05	4028.58	3994.60	3946.08	3883.03
HARVEST COSTS	1373.21	1391.81	1405.33	1413.77	1417.13	1415.41	1408.60	1396.72	1379.75	1357.71
OPERATING COSTS	839.04	825.98	839.04	825.98	839.04	825.98	839.04	825.98	839.04	825.98
OPERATING INCOME	1715.12	1762.77	1774.86	1803.61	1796.81	1806.66	1780.94	1771.90	1727.29	1699.34
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	1715.12	1762.77	1774.86	1803.61	1796.81	1806.66	1780.94	1771.90	1727.29	1699.34
TAX	428.78	440.69	443.71	450.90	449.20	451.66	445.24	442.97	431.82	424.83
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	428.78	440.69	443.71	450.90	449.20	451.66	445.24	442.97	431.82	424.83
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	1286.34	1322.07	1331.15	1352.71	1347.61	1354.99	1335.71	1328.92	1295.47	1274.51

Table 13 continued

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
INTERSTM TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 1	2	3	4	5	6	7	8	9	10
GROSS REVENUE	0.0	0.0	0.0	282.52	796.30	1883.48	2894.64	3244.41	3573.12	3880.78
HARVEST COSTS	0.0	0.0	0.0	87.00	217.50	580.00	891.38	999.09	1100.31	1195.05
OPERATING COSTS	220.54	322.05	374.91	429.97	651.71	666.74	865.08	850.57	865.08	850.57
OPERATING INCOME	-220.54	-322.05	-374.91	-234.45	-162.91	636.74	1138.18	1394.76	1607.73	1835.16
COST RECOVERY	0.0	0.0	0.0	482.00	482.00	482.00	482.00	482.00	0.0	0.0
TAXABLE INCOME	-220.54	-322.05	-374.91	-716.45	-644.91	154.74	656.18	912.76	1607.73	1835.16
TAX	-55.13	-80.51	-93.73	-179.11	-161.23	38.68	164.05	228.19	401.93	458.79
INVEST. CREDIT	0.0	0.0	0.0	241.00	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	-55.13	-80.51	-93.73	-420.11	-161.23	38.68	164.05	228.19	401.93	458.79
CAPITALIZED INV.	2410.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	-2575.40	-241.54	-281.18	-296.34	-483.68	116.05	492.14	684.57	1205.80	1376.37

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
INTERSTM TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 11	12	13	14	15	16	17	18	19	20
GROSS REVENUE	4167.37	4432.92	4677.41	4900.83	5103.20	5284.52	5444.77	5583.97	5702.11	5799.19
HARVEST COSTS	1283.31	1365.08	1440.37	1509.17	1571.49	1627.32	1676.67	1719.53	1755.91	1785.81
OPERATING COSTS	865.08	850.57	865.08	850.57	865.08	850.57	865.08	850.57	865.08	850.57
OPERATING INCOME	2018.99	2217.27	2371.96	2541.10	2666.64	2806.63	2903.02	3013.87	3081.12	3162.81
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	2018.99	2217.27	2371.96	2541.10	2666.64	2806.63	2903.02	3013.87	3081.12	3162.81
TAX	504.75	554.32	592.99	635.27	666.66	701.66	725.75	753.47	770.28	790.70
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	504.75	554.32	592.99	635.27	666.66	701.66	725.75	753.47	770.28	790.70
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	1514.24	1662.95	1778.97	1905.82	1999.98	2104.97	2177.26	2260.40	2310.84	2372.11

Table 13 continued

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
INTERSTM TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 21	22	23	24	25	26	27	28	29	30
GROSS REVENUE	5875.22	5930.18	5964.09	5976.94	5968.74	5939.48	5889.17	5817.80	5725.36	5611.87
HARVEST COSTS	1809.22	1826.15	1836.59	1840.55	1838.02	1829.01	1813.52	1791.54	1763.07	1728.13
OPERATING COSTS	865.08	850.57	865.08	850.57	865.08	850.57	865.08	850.57	865.08	850.57
OPERATING INCOME	3200.92	3253.46	3262.42	3285.83	3265.63	3259.90	3210.57	3175.69	3097.21	3033.18
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	3200.92	3253.46	3262.42	3285.83	3265.63	3259.90	3210.57	3175.69	3097.21	3033.18
TAX	800.23	813.36	815.61	821.46	816.41	814.98	802.64	793.92	774.30	758.29
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	800.23	813.36	815.61	821.46	816.41	814.98	802.64	793.92	774.30	758.29
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	2400.69	2440.10	2446.82	2464.37	2449.22	2444.93	2407.93	2381.77	2322.91	2274.88

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
DWARF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	YEAR 1	2	3	4	5	6	7	8	9	10
GROSS REVENUE	0.0	0.0	0.0	309.43	773.58	2062.88	3170.35	3553.44	3913.46	4250.41
HARVEST COSTS	0.0	0.0	0.0	78.00	195.00	520.00	799.17	895.73	986.49	1071.43
OPERATING COSTS	216.90	364.28	418.93	634.76	793.96	789.35	802.41	789.35	802.41	789.35
OPERATING INCOME	-216.90	-364.28	-418.93	-403.33	-215.38	753.53	1568.78	1868.35	2124.57	2389.64
COST RECOVERY	0.0	0.0	0.0	1064.00	1064.00	1064.00	1064.00	1064.00	0.0	0.0
TAXABLE INCOME	-216.90	-364.28	-418.93	-1467.33	-1279.38	-310.47	504.78	804.35	2124.57	2389.64
TAX	-54.22	-91.07	-104.73	-366.83	-319.85	-77.62	126.19	201.09	531.14	597.41
INVEST. CREDIT	0.0	0.0	0.0	532.00	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	-54.22	-91.07	-104.73	-898.83	-319.85	-77.62	126.19	201.09	531.14	597.41
CAPITALIZED INV.	5320.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	-5482.67	-273.21	-314.20	-568.50	-959.54	-232.86	378.58	603.26	1593.43	1792.23

Table 13 continued

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
DWARF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	11	12	13	14	YEAR 15	16	17	18	19	20
GROSS REVENUE	4564.31	4855.15	5122.93	5367.63	5589.28	5787.86	5963.38	6115.84	6245.23	6351.56
HARVEST COSTS	1150.55	1223.06	1291.36	1353.05	1408.92	1458.98	1503.22	1541.65	1574.27	1601.07
OPERATING COSTS	802.41	789.35	802.41	789.35	802.41	789.35	802.41	789.35	802.41	789.35
OPERATING INCOME	2611.35	2841.94	3029.15	3225.23	3377.95	3539.52	3657.75	3784.83	3868.56	3961.14
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	2611.35	2841.94	3029.15	3225.23	3377.95	3539.52	3657.75	3784.83	3868.56	3961.14
TAX	652.84	710.48	757.29	806.31	844.49	884.88	914.44	946.21	967.14	990.28
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	652.84	710.48	757.29	806.31	844.49	884.88	914.44	946.21	967.14	990.28
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	1958.51	2131.45	2271.87	2418.92	2533.46	2654.64	2743.31	2838.63	2901.42	2970.85

AFTER TAX CASH FLOW COMPONENTS
NEW YORK STATE
DWARF TREES

TAX BRACKET = 0.25 COST RECOVERY PERIOD = 5

COMPONENT	21	22	23	24	YEAR 25	26	27	28	29	30
GROSS REVENUE	6439.83	6495.02	6532.17	6546.24	6537.26	6505.22	6450.11	6371.94	6270.70	6146.40
HARVEST COSTS	1622.06	1637.23	1646.60	1650.15	1647.88	1639.80	1625.91	1606.21	1580.69	1549.35
OPERATING COSTS	802.41	789.35	802.41	789.35	802.41	789.35	802.41	789.35	802.41	789.35
OPERATING INCOME	4010.36	4068.43	4083.16	4106.73	4086.97	4076.06	4021.79	3976.38	3887.59	3807.69
COST RECOVERY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAXABLE INCOME	4010.36	4068.43	4083.16	4106.73	4086.97	4076.06	4021.79	3976.38	3887.59	3807.69
TAX	1002.59	1017.11	1020.79	1026.68	1021.74	1019.02	1005.45	994.09	971.90	951.92
INVEST. CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET TAX PAID	1002.59	1017.11	1020.79	1026.68	1021.74	1019.02	1005.45	994.09	971.90	951.92
CAPITALIZED INV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AFT. TAX CASH FL	3007.77	3051.32	3062.37	3080.05	3065.22	3057.05	3016.34	2982.28	2915.70	2855.77

RESULTS AND SENSITIVITY

There are two groups whose interests may be served by this orchard replacement model. Researchers in agricultural economics and pomology may be interested in the performance of the model under varying assumptions and the validity of its results both from a theoretical standpoint and in comparison with the current farm situation. Growers will be interested in knowing how different economic and pomological conditions or various levels of managerial skill can affect the optimal replacement decision.

It is the consensus of pomologists, extension agents, and agricultural economists that the apple industry trend is toward higher-density plantings. This feeling is supported by the 1980 Orchard and Vineyard Survey, which shows that proportionately fewer standard trees were planted in the last few years than semi-dwarf, interstem or dwarf trees. Initially, only the more progressive growers considered higher-density plantings, but now more growers who face the replacement decision or who are establishing new plantings are considering interstem or dwarf trees. In the middle 1970's, dwarf tree plantings on trellis or pole support systems were being recommended to those growers who wanted higher-density planting systems. When the price of poles doubled (Norton), many growers and extension agents began to question whether dwarf plantings with relatively expensive support systems were any longer the best system. Interstem trees seemed to be the logical answer, and for the past three or four years recommendations have leaned heavily toward interstem plantings.

Experimental Design

The replacement model was run using New York State average cost, price, production, and yield data. True to current field recommendations, the model responded by suggesting immediate replacement with interstem planting systems for standard trees of all ages and semi-dwarf trees younger than nine years of age. Interstem and dwarf planting systems are kept until they reach their final year of economic life, in this case 30 years. Replacement with interstem planting systems was again optimal.

These results are based on New York State averages. Since each orchard has its unique charactierstics, the important question is how sensitive is the model to above or below average orchard management and under what conditions might another system be optimal? In order to answer this question, sensitivity analysis was conducted. A decision was made to concentrate on the area of fruit quality and yield for several reasons:

1) Evaluating the effect upon the results of changing each input would require too many permutations. Input quantities were thus ruled out in the interest of brevity and expense.

2) Close scrutiny reveals that variable costs of production per acre are not vastly different between the four planting systems. Costs are not the determining factor in the choice of optimal replacement orchard.

3) Yield and fruit quality have been recognized by the industry, extension agents, pomologists, and agricultural economists as the

keys to successful apple production for many years. By varying yield and/or percentage packout of high quality fruit, it is possible to examine several possible levels of management and their effect upon the optimal orchard replacement decision.

4) Beyond examination of the management question, it is also possible, to a limited extent, to analyze the effects of different levels of risk upon the optimal replacement decision, using adjusted yield and fruit quality levels.

In addition to testing the model for sensitivity to yield and packout (quality), two different real discount rates were used and their effects upon the optimal replacement decision analyzed. Except for discount rate, the standard planting data remains constant. The following analyses were made:

1) No change - two runs, one at three percent real discount rate, one at seven percent real discount rate.

2) Drop yield by 10 percent - six runs, one for each real rate of discount, and for yield change in semi-dwarf, interstem, and dwarf systems.

3) Increase yield by 10 percent - six runs, one for each real rate of discount, and for yield change in semi-dwarf, interstem, and dwarf systems.

4) Decrease percent packout of top quality fruit by 10 percent, making appropriate adjustments in other qualities - six runs, one for each real discount rate and for packout change in semi-dwarf, interstem, and dwarf systems.

5) Decrease percent packout of top quality fruit by 10 percent and decrease yield by 10 percent - six runs, one for each real discount rate and for packout change in semi-dwarf, interstem, and dwarf systems.

6) Decrease percent packout of top quality fruit by 10 percent and increase yield by 10 percent - six runs, one for each real discount rate and for changes in semi-dwarf, interstem, and dwarf systems.

The model was initialized for each of these 32 runs by starting with a planting of standard trees 25 years old, using a five-year cost recovery period and a 25 percent marginal tax bracket. The five-year cost recovery period is the shortest allowed for orchards under the 1981 Economic Recovery Act, and it was assumed that most growers would elect the shortest period possible.

Results and Model Sensitivity

The results of the 32 optimization runs are summarized in Tables 14, 15, and 16. Examining the results of changes made on semi-dwarf trees (Table 14), the first column on the left reveals that interstem trees are always the optimal replacement system under all yield and packout

Table 14. Replacement Results with Selected Yield and Packout Changes for Semi-Dwarf Planting Systems

Change Made*	Replacement System	NPV of Replacement System	Standard		Semi-Dwarf		Interstem		Dwarf	
			Ages	NPV Range	Ages	NPV Range	Ages	NPV Range	Ages	NPV Range
			3% Real Rate							
N	Interstem	$33,636	all	—	30, 1-8	$33,951-36,920	30	$34,979 51,066	30	$35,572 59,415
1	Interstem	33,636	all	—	30, 1-12	34,979-34,934	30	34,979-51,066	30	35,572-59,415
2	Interstem	33,636	all	—	30, 1-6	34,144-39,012	30	34,979-51,066	30	35,572-59,415
3	Interstem	33,636	all	—	30, 1-10	33,835-35,694	30	34,979-51,066	30	35,572-59,415
4	Interstem	33,636	all	—	30, 1-16	33,654 34,012	30	34,979-51,066	30	35,572 59,415
5	Interstem	33,636	all	—	30, 1-7	34,016-37,621	30	34,979-51,066	30	35,572-59,415
			7% Real Rate							
N	Interstem	$ 8,293	all	—	30, 1-4	$ 9,047-14,902	30	$10,073-25,765	30	$10,666-31,791
1	Interstem	8,293	all	—	30, 1-5	8,396-13,142	30	10,073-25,765	30	10,666-31,791
2	Interstem	8,293	all	—	30, 1-2	8,834-16,700	30	10,073-25,765	30	10,666-31,791
3	Interstem	8,293	all	—	30, 1-5	8,930-13,837	30	10,073-25,765	30	10,666-31,791
4	Interstem	8,293	all	—	30, 1-6	8,375-12,191	30	10,073-25,765	30	10,666-31,791
5	Interstem	8,293	all	—	30, 1-3	8,733-15,506	30	10,073-25,765	30	10,666-31,791

*Changes:
1. Reduce yield by 10 percent.
2. Increase yield by 10 percent.
3. Decrease percent packout top quality fruit by 10 percent.
4. Change 3 + Change 1.
5. Change 3 + Change 2.
N. No changes made. Data is state average, "default" data in model.

combinations tested and for both real discount rates. The second column from the left gives the net present value (NPV) of the replacement system. This is the NPV of following the replacement policy from the year in which the replacement was made. Columns three and four of Table 14 show the ages at which standard trees should be replaced. The NPV is always the NPV for replacement with interstem trees under the real discount rate assumed, as standard trees should be replaced regardless of the age of the current orchard.

For the semi-dwarf category the results are more interesting. Column five, row one, three percent interest rate, for example, suggests that a semi- dwarf orchard which is currently less than nine years old should be replaced next year with interstem trees. Semi-dwarf trees aged nine years through 29 years should be kept.

The sixth column, "NPV Range", for semi-dwarf trees, gives the range of the NPV of the semi-dwarf planting system under the "keep" alternative. The NPV of any orchard at any age is calculated by summing the discounted positive and negative after-tax cash flows when following the optimal replacement policy. When establishing an orchard, there is a large initial cash outlay in the establishment year, followed by a few years during which operating expenses are incurred with no offsetting income. In the NPV calculation, these early years of negative after-tax cash flows are weighted heavily because they are discounted least. The result is that a one year old semi-dwarf orchard will have a lower NPV than a two year old semi-dwarf orchard, simply because at age two there is one less negative after-tax cash flow to be subtracted from NPV. As the model looks at established semi-dwarf orchards which are of increasing age, NPV first becomes higher, reaches a peak, then begins to decline. Each subsequent stage in the dynamic programming model represents an orchard of one year older, unless the orchard is 30 years old, in which case the next stage represents a new orchard of the same or of a different type. As the model advances one stage, representing a year in the life of a particular type of orchard, the NPV for that orchard is augmented or reduced according to whether the orchard was producing a negative or positive after-tax cash flow in the last stage.

The remaining four columns of Table 14 show that for both real discount rates and under each of the yield and packout situations for the semi-dwarf orchard, it is always optimal to keep established interstem and dwarf plantings until they are 30 years old. The major effect of increasing the real discount rate is to reduce the absolute size of all of the NPV's and to lower the ages of semi-dwarf plantings for which replacement is optimal.

Changing yield and packout levels for semi-dwarf trees tends to affect only semi-dwarf plantings. Lower yields or lower quality tend to increase the number of years after planting in which it is optimal to remove a semi-dwarf orchard and replace it with an interstem planting. Increasing yields or packout of high quality fruit tends to lengthen orchard age during which it is optimal to keep semi-dwarf plantings, by allowing the "keep" decision for younger orchards. Yield has a greater affect upon the optimal decision than quality. The change in ages over which replacement is optimal is greater for adjustments in yield than for adjustments in quality mainly because the changes in yield are a percent of yield and the changes in quality are a percent of a percent of yield.

Table 15 shows the results of making the same changes that were made for semi-dwarf trees on the interstem orchard. The first column from the left under the three percent real discount rate shows that the model is extremely sensitive to changes in yield and quality for the interstem planting system. Reduction in yield, packout or both of only 10 percent make replacement with the dwarf planting system optimal. With a seven percent real discount rate, however, the interstem system is always optimal. The high initial expense of establishing a dwarf planting outweighs the higher quality fruit obtained during the producing years under the higher discount rate. The second column of Table 15 shows that the NPV of the interstem system is highly variable under both real discount rates. This is because the interstem system is the system undergoing changes, and the changes are reflected in NPV.

An interesting situation arises in Table 15 under the seven percent real discount rate. When interstem yields and packout are both dropped by 10 percent, it becomes optimal to keep standard trees between the ages of 23 and 30, replacing them at age 30 with interstem trees. This is the only situation in the entire analysis in which it is optimal to keep standard trees of any age. The implications, aside from an illustration of model sensitivity, are that if growers cannot obtain high yields and high quality fruit from the newer plantings, then there are cases in which keeping old standard trees remain optimal.

As in Table 14, the ages in which semi-dwarf plantings should be replaced change according to which system is optimal for replacement and changing yield and quality conditions. Worthy of note is that if yield and top quality are both reduced by 10 percent for interstem trees, the dwarf system becomes the optimal replacement system under the three percent real discount rate, and interstem trees just established (one year of age) should be removed and replaced with a dwarf planting. The implication is that, under reduced yield and quality conditions for interstem trees, the expense of establishing a dwarf planting in the year immediately following establishment of an interstem planting on the same piece of land is still outweighed by the higher yield and quality that can be obtained from a dwarf system.

Model sensitivity is again exhibited in Table 16, and the expected results are obtained as changes in yield and quality are made. Under the three percent real discount rate, the dwarf system becomes the optimal replacement system if dwarf yields are increased 10 percent, and if packout of top quality fruit is reduced by 10 percent but yields are increased by 10 percent. This is consistent with the results in Table 15.

Under the seven percent real discount rate, the interstem system is always the optimal replacement system. Under both discount rates, with a reduction in both dwarf yield and quality, it becomes optimal to replace a newly established dwarf orchard with interstem trees. Otherwise it is optimal to keep dwarf and interstem plantings until age 30, except when dwarf yields are increased by 10 percent and it becomes optimal to remove a newly established interstem planting and replace it with a dwarf planting.

Table 15. Replacement Results with Selected Changes for Interstem Planting Systems

Change Made*	Replacement System	NPV of Replacement System	Standard		Semi-Dwarf		Interstem		Dwarf	
			Ages	NPV Range	Ages	NPV Range	Ages	NPV Range	Ages	NPV Range
			3% Real Rate							
N	Interstem	$33,636	all	—	30, 1-8	$33,951-36,920	30	$34,979-51,066	30	$35,572-59,415
1	Dwarf	33,128	all	—	30, 1-8	34,459-36,574	30	33,309-46,700	30	34,079-59,134
2	Interstem	33,865	all	—	30, 1-12	40,000-41,278	30	41,324-58,756	30	41,620-62,904
3	Dwarf	33,128	all	—	30, 1-8	33,459-36,574	30	34,301-48,223	30	35,079-59,134
4	Dwarf	33,128	all	—	30, 1-8	33,459 36,574	30	34,022-44,436	30	35,079-59,134
5	Interstem	33,596	all	—	30, 1-9	34,855-38,255	30	35,855-38,255	30	37,475-60,501
			7% Real Rate							
N	Interstem	$ 8,293	all	—	30, 1-4	$ 9,047-14,902	30	$10,073-25,765	30	$10,666-31,791
1	Interstem	6,058	all	—	30, 1	6,344-14,091	30	7,687-23,071	30	8,577-31,130
2	Interstem	10,528	all	—	30, 1-5	10,561-15,761	30	12,460-29,459	30	11,569-31,955
3	Interstem	6,901	all	—	30, 1-2	7,179-14,397	30	8,587-23,464	30	9,365-31,379
4	Interstem	4,805	30, 1-22	$4,818-4,887	30, 1	5,786-13,661	30	6,350-20,000	30	7,406-30,759
5	Interstem	8,997	all	—	30, 1-4	9,263-15,167	30	10,825-26,928	30	11,324-31,999

*Changes:
1. Reduce yield by 10 percent.
2. Increase yield by 10 percent.
3. Decrease percent packout top quality fruit by 10 percent.
4. Change 3 + Change 1.
5. Change 3 + Change 2.
N. No changes made. Data is state average, "default" data in model.

Table 16. Replacement Results with Selected Changes for Dwarf Planting Systems

Change Made*	Replacement System	NPV of Replacement System	Standard		Semi-Dwarf		Interstem		Dwarf	
			Ages	NPV Range	Ages	NPV Range	Ages	NPV Range	Ages	NPV Range
			3% Real Rate							
N	Interstem	$33,636	all	—	30, 1-8	$33,951-36,920	30	$34,979-51,066	30	$35,572-59,415
1	Interstem	33,636	all	—	30, 1-8	33,951-36,920	30	34,979-51,066	30	35,220-54,454
2	Dwarf	40,501	all	—	30, 1-12	40,565-41,740	30	41,645-55,071	30	42,589-68,210
3	Interstem	33,636	all	—	30, 1-8	33,951-36,920	30	34,979-51,066	30	35,387-56,787
4	Interstem	33,636	all	—	30, 1-8	33,951 36,920	30	34,979-51,066	30	35,053-52,134
5	Dwarf	36,233	all	—	30, 1-9	36,473-38,704	30	37,500-52,564	30	38,241-62,926
			7% Real Rate							
N	Interstem	$ 8,293	all	—	30, 1-4	$ 9,047-14,902	30	$10,073-25,765	30	$10,666-31,791
1	Interstem	8,293	all	—	30, 1-4	9,047-14,902	30	10,073-25,765	30	10,315-28,215
2	Interstem	8,293	all	—	30, 1-4	9,047-14,902	30	10,073-25,765	30	11,018-35,367
3	Interstem	8,293	all	—	30, 1-4	9,047-14,902	30	10,073-25,765	30	10,481-29,900
4	Interstem	8,293	all	—	30, 1-4	9,047-14,902	30	10,073-25,765	30	10,148-26,526
5	Interstem	8,293	all	—	30, 1-4	9,047-14,902	30	10,073-25,765	30	10,814-33,297

*Changes:
1. Reduce yield by 10 percent.
2. Increase yield by 10 percent.
3. Decrease percent packout top quality fruit by 10 percent.
4. Change 3 + Change 1.
5. Change 3 + Change 2.
N. No changes made. Data is state average, "default" data in model.

In making the replacement decision, yield, fruit quality, and the discount rate are the crucial determinants of whether interstem or dwarf plantings are the optimal replacement system. The higher the discount rate, the less attractive the dwarf planting system becomes, because of its required high initial outlay for establishment. At low real discount rates, the tradeoffs between dwarf and interstem planting systems become dependent upon expected differential yields and fruit quality.

SUMMARY AND CONCLUSIONS

The primary objective of this research was to develop an orchard replacement model. It consists of a simulation model, which is capable of modification using some or all of the data from a grower's own operation to obtain a series of after- tax cash flows for four apple orchard planting systems over a 30-year economic life. These after-tax cash flows are then utilized in a dynamic programming model to choose the optimal planting system and the optimal time of replacement, under varying assumptions regarding the grower's tax bracket, choice of cost recovery period, and real rate of discount.

The development of an orchard replacement model of this type has several implications:

1) For growers, a tool now exists which enables determination of the optimal replacement time and the optimal replacement orchard system on an individual farm level. This is a practical, usable decision aid which is limited mainly by the judgement of the user in the choice of discount rate and in the estimation of managerial ability.

2) For researchers, the model produces viable, consistent, and believable results. This will allow the testing of new ideas and even new products such as spray materials, and their effects upon the optimal replacement decision.

3) This is the first application of dynamic programming to the orchard replacement problem. Though there are some limitations to the methodology, it is an improvement over previous orchard replacement decision models, if only because it operates in a truly dynamic framework.

4) The effects of taxes on farm or business decisions are extremely important. This model includes the effects of some of the current tax laws in its analysis.

There has been a shift in recent years in the recommendations that pomologists and extension agents have been making to growers regarding the best new planting system to use, whether for replacement or in the original establishment of an orchard. The shift has been from dwarf plantings, which require relatively expensive support systems, to interstem trees. The results of this model show that the recommendations are generally correct; at least the results agree with current recommendations.

If a user feels that the real discount rate should be relatively low (three percent) then the question of which system, dwarf or interstem, is optimal, depends upon yields and fruit quality. If the real discount rate is expected to be higher (seven percent), the interstem planting system is consistently preferable, under the many different levels of management tested. These results are consistent with what one would expect to find in the industry. The factors affecting the optimal replacement time and choice of the optimal orchard replacement system, in declining order of importance, are:

1) The rate of discount, in this case, the real rate of discount.

2) The expected yields which can be obtained from a planting system.

3) The expected quality of fruit which can be obtained from a planting system as defined by percent packout of the top grade of fruit.

It is recognized that there are other factors which could have an affect upon the optimal replacement decision. One of these is the year in which a planting system actually begins commercial production. Obviously, the earlier a system can be brought to commercial production, the more profitable and the more desirable that system will be. The times at which the four systems come into production in the model were chosen based on the perceptions of extension agents, pomologists, and agricultural economists, about the situation most likely to occur in the industry today, as well as the results of previous studies (Khera and Crowe, Norton, Gerling). Individual growers or researchers may have other opinions, and inserting these into the model may affect the choices of the optimal system. Of course, this flexibility for each input in the model is one of the strengths of the model.

There are some limitations with the model:

1) It does not say "how much" to replace. That decision is left to the grower. The analysis is constructed on a per acre basis, which gives extreme flexibility in the size of blocks under consideration for replacement, since an analyst can use increments or multiples of one acre.

2) The model does not consider financial feasibility. This is directly related to the first limitation (above) but it also concerns the possible inability of the grower to afford a system such as the dwarf system, since it requires such a large initial outlay.

3) Replant disease problems have not been accounted for.

In conclusion, this model should serve as an addition to the decision tools available to farmers and as an important analytical tool to researchers. With some modifications, it can be adapted for use with small computers, adding to the available software for agricultural use.

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