Optimal replacement of alfalfa stands
by Glen Irvin Goodman

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Applied Economics
Montana State University

Abstract:
This study investigates the optimal stand length of irrigated alfalfa hay. A dynamic decision model is solved which determines the optimal decision (grain or continuation of an existing alfalfa stand) for 275 possible states of the system (25 price states for each of 11 land use states). The problem is solved for specified production practices and interest rates. The decision criterion is to maximize the net present value of future returns from irrigated crops in Montana river valleys. Both pure stands and companion crop stands of alfalfa are examined. Alfalfa replacement is found to take place between seven and eight years of stand life. The decision rule is relatively insensitive to interest rates and nearly identical for both the pure and companion crop stands. A pure stand of alfalfa is found to be slightly more profitable than an alfalfa stand seeded with a companion crop.

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Signature Glen D. Goodman

Date May 10, 1982

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ABSTRACT

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Chapter 1

INTRODUCTION

Alfalfa (Medicago sativa L.) is the most important hay crop in Montana with approximately 1,260,000 acres presently seeded. This accounts for 53 percent of the total hay acreage in the state (10). Its primary use in state is for the feeding of livestock with the residual being transported out of the state for sale.

Alfalfa's popularity is derived from the fact that it is a perennial crop (can sustain harsh winters) with a greater yield and higher nutrient content per acre than most competing forage crops (8). Also, in cooperation with bacteria, alfalfa has the ability to utilize atmospheric nitrogen. The amount of nitrogen has been conservatively estimated at 74 to 90 pounds per acre, making it a desirable crop in rotations (8).

The 1980 Montana alfalfa crop was valued at $173,000,000, trailing only spring and winter wheat in value (10). Because of these desirable qualities alfalfa has been designated "queen of the forage crops" by research agronomists.

Because of alfalfa's significant economic value, improvement in its management offers substantial monetary returns. One of the important questions facing alfalfa producers is when to replace an established stand of alfalfa with a new stand. The purpose of this study was to determine the optimal age to replace alfalfa stands.

Problem Statement

Since alfalfa was first introduced in Montana, farmers have used rather intuitive "rules of thumb" in deciding when to replace alfalfa stands. The aim of this research is to develop an economic decision model, which will allow farm managers to make optimal decisions regarding replacement of alfalfa stands.

The goal of replacement theory is to maximize the economic returns from an asset over time. This is accomplished by selecting a particular production period which yields the maximum net present value of future returns. The decision model developed should achieve this goal and also be general enough to allow for the production of alternative crops such as barley, if the returns from the alternative crops are superior to the returns from an alfalfa stand of optimal duration.

Objectives

The primary objective of this thesis is to develop a decision making model for Montana farmers, with the intended purpose of increasing the economic returns from alfalfa production in Montana's irrigated crop areas. An economic replacement model cast in a dynamic programming framework will be used to determine the optimal policy for replacing irrigated alfalfa stands. The dynamic replacement model will be solved for specified production practices, interest rates and product prices representing most conditions encountered on irrigated crop farms in Montana.

Chapter 2

LITERATURE REVIEW

The principles and techniques of the articles reviewed in this section are essential for the model development of this study.

The reviewed literature is divided into three categories: 1) optimum replacement patterns and principles; 2) dynamic programming decision models; and 3) alfalfa management.

Optimum Replacement Patterns and Principles

Anthony Chisholm (2), R. K. Perrin (13) and Martin Upton (17) have contributed to the understanding and implementation of asset replacement theory. (It should be noted that a German forester, Martin Faustman [1849] is credited with the first application of discounted cash flows to a replacement problem.)

Chisholm [1966] asserts the general premise of replacement as being able to select the particular production period over a predetermined planning horizon which will maximize the net present value of future returns.

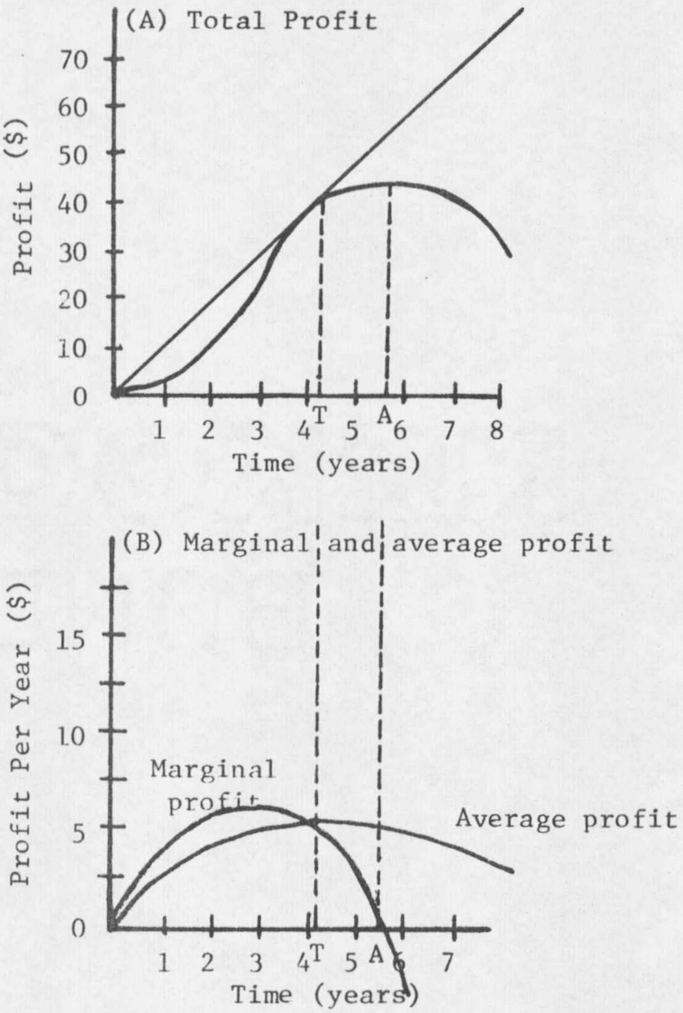
Perrin [1972] characterizes replacement as the goal of an asset manager wanting to maximize the net present value of a future stream of income associated with the asset. The actual replacement problem according to Perrin is choosing the replacement age which maximizes the net present value of cash flows attributed to an asset.

Upton [1976] illustrates replacement theory graphically. An illustration of his graphical analysis in production theory framework is depicted in Figure 1.

Chisholm [1966] addresses the opportunity cost considerations of replacement theory. He defines the relevant opportunity costs in replacement as ones which are involved in the fixed and variable costs as well as the funds tied up in the actual replacement asset under study. Chisholm concludes by stating that the relevant opportunity costs should be compounded at an appropriate rate of interest in order to compare costs and returns incurred at differing points in time.

Perrin [1972] elaborates on the choice of a discount rate. The cost of capital, return on alternative investment possibilities, or timing of personal consumption are alternative choices when deriving a discount rate according to Perrin. He further states that although neither of these are universally recognized, the choice of discount rate depends on the circumstances at hand. That is, the presence of perfect capital markets, "destitute" owners who value future earnings quite low relative to present earnings, or a fixed capital stock with no accessible external capital markets are all factors which affect the appropriate rate of discount.

Perrin also makes the distinction between continuous and discrete time. He believes that in most replacement problems, net revenues and



"Profit is represented as a function of the length of the production period in the upper graph (A). The lower graph (B) shows the average and marginal net profits per year over the production period. Maximum profit for a single non-repeated project is found where the marginal profit from prolonging it is zero (i.e. at project life of OA years). However, maximum profit per unit of time is found where marginal profit from prolonging the project is equal to the average profit per year (i.e. at a project life of OT years)."

Figure 1. Optimization Over Time

Source: Upton, Martin. Agricultural Production Economics and Resource Use. Oxford University Press [1976].

market values are observed as discrete annual levels.

Perrin also notes that evaluating the present values of the returns associated with an asset is often a better search procedure than evaluating the marginal criteria. The reason he states, is that there is a possibility of encountering a one year error when making a marginal decision.

It should be recognized that not one application of replacement theory to the optimal replacement of alfalfa stands was found in the literature.

Dynamic Programming Decision Models

Optimum replacement models can be formulated using the procedures of dynamic programming. Early applications of dynamic programming to replacement problems were made by Ronald Howard (5), with early applications to agricultural production problems by Oscar R. Burt and John R. Allison (1). Frederick S. Hillier and Gerald J. Lieberman (4) have published a contemporary textbook which contains a good discussion of dynamic programming.

Hillier and Lieberman [1980] define dynamic programming as a mathematical search procedure often useful for making a sequence of interrelated decisions. They conclude their description by characterizing dynamic programming as a systematic procedure which can determine the combination of decisions that maximizes overal efficiency.

Burt and Allison [1963] clarify the concept of dynamic programming in their work, by describing it as a multistage decision process which involves finding a sequence of decisions which maximizes an appropriately defined objective function. The stages are intervals into which the process is divided, with a decision being made at each stage. A sequence of these stages comprises the decision process. Burt and Allison go on to define a state as the condition of a process at a particular stage. This is defined by the magnitude and/or qualitative characteristics of the variables involved. Burt and Allison conclude their conceptual description of dynamic programming by placing it in a decision framework. That is, the state of a process in the following stage is controlled by the decision making at the present stage. The control can be either deterministic or stochastic.

Hillier and Lieberman [1980] describe the Markovian requirement of dynamic programming by stating that the optimal policy starting in a given state depends only on the state of the process in that stage and not on the state at preceding stages. They also comment on the recursive relationship that is present in dynamic programming models. Hillier and Lieberman note that the relationship allows the solution procedure to move backward stage by stage, finding an optimal policy at each state of the stage, until an optimal policy is found when starting at the initial stage.

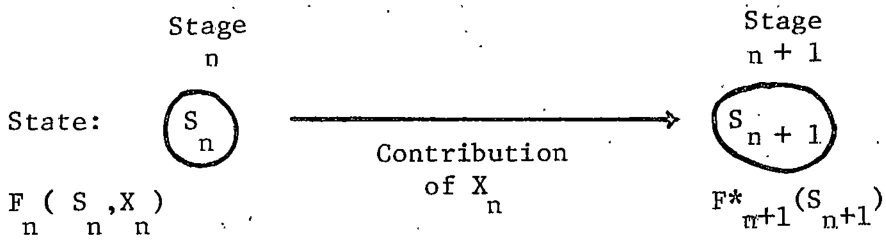
Hillier and Lieberman graphically illustrate the basic structures of deterministic and stochastic dynamic programming models. The basic structures are presented in Figures 2 and 3.

The differences between the models are clearly illustrated. That is, the state of the next stage is not solely determined by the present state and policy decision of the current stage, in the stochastic model. There is, instead, a probability distribution for determining the next state in the new stage. Hillier and Lieberman note that the probability distribution is a function of the current state and policy alternative at the current stage only.

Howard [1960] sets up an automobile replacement problem using dynamic programming. The planning horizon is designated as ten years with a replacement decision being made every three months. He describes the state of the system (i), as the age of the car in three month periods, with (i) running from 1 to 40. In order to keep the number of states finite, Howard considered a car of age 40 essentially worn out. Howard defines the decision alternatives available in each state as S = 1, keep the present car for another quarter, or S > 1, buy a car of age S - 2. Thus, Howard defines a replacement problem with 40 states and 41 alternatives in each state.

Alfalfa Management

Data involving alfalfa production has been drawn on from Extension research studies in Montana. Specific references are: Montana



n = Stage

S_n = State

$F_n(S_n, X_n)$ = Objective Function

X_n = Policy Decision

Figure 2. Deterministic Model for Dynamic Programming.

Source: Hillier, Frederick S. and Lieberman, Gerald J. <u>Introduction to Operations Research</u>. Holden-Day, Inc. [1980].