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ALFALFA PRODUCTION AS RELATED TO IRRIGATION SCHEDULING: AN ECONOMIC PERSPECTIVE

by

Craig L. Israelsen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

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Approved:

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Craig L. Israelsen

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ABSTRACT

Alfalfa Production as Related to Irrigation Scheduling: An Economic Perspective

by

Craig L. Israelsen, Master of Science
Utah State University, 1984

Major Professor: Dr. Donald L. Snyder
Department: Agricultural Economics

This study analyzed the economics of irrigation scheduling for alfalfa hay in the Cache Valley, Utah area. Yield, evapotranspiration (ET) and irrigation drainage loss, along with the costs and returns per acre attributable to irrigation scheduling, were simulated through the use of a computerized plant growth model. The model created yearly "irrigation schedules" for alfalfa hay based on actual climatic, soil and plant characteristic data from the Utah State University Greenville Experiment Station. The model calculated the irrigation schedules based on a soil-water balance equation which never allowed the available soil water to go below the crop stress point.

The production variables (yield, ET, drainage, water application efficiency) achieved with the model-calculated schedules were contrasted against the same variables under conventional practices of zero, five and eight irrigations

per season. Under five and eight irrigations, the amount of water applied at each irrigation was varied from one to eight inches, which simulated irrigations ranging from 3.4 to 26.6 hours per set.

The yearly irrigation schedules created by the soil-water balance equation maximized crop evapotranspiration and yield. Irrigation drainage was negated while water application efficiencies of 100% were achieved by applying only enough water at each irrigation to refill the soil profile.

Using model-estimated yield, net profit for each irrigation option (scheduling, zero, five and eight irrigations) was calculated using nine different irrigation cost scenarios. Based on the 16 years of simulation, irrigation scheduling averaged a lower net profit when compared against five irrigations at three and four inches per irrigation. Compared against eight irrigations at two and three inches per irrigation, net profit for the model-calculated schedules averaged higher or equal.

Irrigation scheduling is an excellent method of determining optimal irrigation frequency and amount, and may have a significant impact on net income if an irrigator is substantially over or under irrigating. However, once an optimal pattern of irrigations is established using a scheduling technique it may be more profitable for an irrigator to discontinue incurring the cost of irrigation scheduling and simply use the pattern each successive

season, modifying it slightly for annual variations in climate.

(95 pages).

CHAPTER I

INTRODUCTION

Cost minimizing farm and ranch management techniques are becoming increasingly important in this day of unstable commodity prices and increasing input costs. The ability to lower production costs through the adoption of innovative management techniques has the potential of raising net farm income, given that prices remain constant. Irrigation scheduling is a management technique which has been recognized as a superior method of irrigating in order to conserve water, increase yields and reduce drainage and runoff (U.S. Environmental Protection Agency 1980). Its impact on net farm income, however, is often neglected. The main focus of this research was to examine potential economic impacts of alfalfa production under irrigation scheduling in the Cache Valley area of Utah. The probable effects on yield, irrigation drainage and other production factors were also included.

Irrigation scheduling, as used in this paper, is meant to denote a a procedure in which the application amount and interval between each irrigation are actually calculated, not arbitrarily assigned or fixed. Irrigation scheduling is essentially putting on the optimal amount of water at the proper time. Several methods can be used to calculate irrigation schedules. One approach requires monitoring the soil moisture with devices such as electrical resistance blocks, tensionmeters, neutron probes or lysimeters. Another method of scheduling calls for irrigations at certain stages in the crop's growth. The method employed in this research was to determine the irrigation schedule based on a water balance equation. The water balance equation keeps track of the water entering the soil and predicts the amount leaving in the form of evapotranspiration (ET). ET is estimated from very recent or long term averaged climatic data with equations such as the Penman equation, Blaney-Criddle equation, and others. It can also be estimated from pan evaporation, a measure of free water evaporation. In either case, data regarding the specific soil and plant characteristics, climate, and irrigation system used are needed by the water balance equation. The specific water balance equation used will be shown later.

The underlying principle of irrigation scheduling, as opposed to "scheduled irrigations" or simply irrigating on a certain day each month or at regular intervals during the growing season, is to maximize evapotranspiration (ET) by not allowing the moisture level of the soil to be depleted below the crop stress point. (ET is broken down into soil evaporation (E) and crop transpiration (T) which together represent total crop water use. Only transpiration contributes towards plant growth hence maximizing T is the real objective). By achieving maximum ET it is felt that maximum yield is also attained (Hanks 1983). Irrigation drainage loss is minimized, even negated, because the water holding capacity of the soil is never exceeded during an irrigation. These two features of irrigation scheduling make it very appealing at first inspection. The deciding factor for adopting new technology, however, is usually an economic incentive.

Statement of the Problem

In recent years electricity rates have increased nearly fourfold causing farmers to search for more efficient irrigation methods in order to reduce pumping costs. In some parts of the arid west an increasing scarcity of water, whether by drought or excess demand, has prompted farmers to seek out ways of making their water allotment stretch further. Agriculture's demand for water is so heavy that in California alone alfalfa uses more water than the 22 million people who live in the state ("Know How Much to Apply", 1983).

In addition to rising pumping costs and shortages of water for agriculture, prices for farm products have been unsteady and declining in real terms. This instability introduces a further incentive to reduce farm production costs through new management practices, one option being irrigation scheduling.

The imperfect nature of the market for water that exists in some parts of the western United States results in an abundance of free or very inexpensive water. This often precludes or hinders the development of cost minimizing technologies. This is especially true for farmers who do not have to pump their irrigation water. These individuals incur no pumping cost despite applying large amounts of water. With no apparent economic penalty for waste, water is often applied in greater amounts than would be needed to achieve maximum, or potential, yields. In acuality, the costs of over-irrigation, as well as under-irrigation, may be significant. Hence, this study has some implications for both situations.

Objectives of the Study

The primary objective of this research is to determine whether or not irrigation scheduling is economically superior to conventional methods of irrigation, including non-irrigation. The specific objectives are:

1. To simulate crop production under four different irrigation options, one being non-irrigation;
2. to determine the effect of the different options on yield, irrigation drainage, evapotranspiration, application efficiency, and net returns per acre;
3. to compare the net profitability of the different options under alternative irrigation cost structures; and
4. to provide a basis for objective economic evaluation of irrigation scheduling on alfalfa hay in comparison with common local methods of irrigating and non-irrigation.

Study Area and Modeled Crop Description

The climatic and soil characteristics data used in the model are from the Utah State University Greenville Experiment Station located approximately two miles north of Utah State University. The farm is geographically located at a longitude of 111 49' and latitude of 41 46'. The elevation of the farm is 4608 feet above sea level with a normal growing season of 160 days (frost free period). The normal yearly precipitation at the U.S.U. Experiment Station is approximately 18 inches (1940-70) with the amount between April 15 and September 10 (the effective growing season used for this research) averaging 6.3 inches for the 16 years of data used. The 1951-1980 average rainfall from April 1 to September 1 was 7.79 inches.

The soil at the U.S.U. Experiment Station is classified as Millville silt loam having a slope of two to four percent. This soil is easily tillable, well drained and permeability is moderate. The water holding capacity (WHC) of the soil is 8 to 10 inches at a depth of 5 feet, or 1.6 to 2 inches per foot of soil. Runoff is slow and therefore the erosion hazard is minimal. Roots can easily penetrate the soil to a depth of 5 or more feet. The soil is classified into 5 different horizons at intervals of 0-6, 6-12, 12-24, 24-35, and 35-65 inches. The entire profile is moderately alkaline and very strongly calcareous. This type of soil is used mostly to grow irrigated crops such as alfalfa, small grains, corn for silage, sugar beets, small grains, peas, and pole beans (U.S. Dept. of Agriculture 1974). Alfalfa hay was chosen as the crop to model because it is the predominant crop grown in Utah, comprising nearly 40% of harvested cropland in the state as of 1978. In 1981, Cache County lead the state with 51,800 acres devoted to alfalfa production, or 45% of its harvested cropland (Utah State Dept. of Agriculture 1982). Alfalfa hay is also a crop that depends heavily upon irrigation. As of 1978, 90% of alfalfa hay in the state was under irrigation, while in Cache County 65% was irrigated (U.S. Dept. of Commerce 1978). In 1981 the "on-farm" production value of all hay in Utah was estimated at $132,253,000, 90% being alfalfa hay. Thirty percent of the total cash receipts for Utah crops in 1980 came from the sale of alfalfa hay, representing a 12% increase since 1960 (Utah State Dept. of Agriculture 1982).

Procedures and Methodology

A computerized plant growth model using actual climatic data was employed to simulate alfalfa production under three different irrigation schemes, and one non-irrigation scheme. Each method was analyzed in terms of its impact on total crop production and related factors, total irrigation cost and net return per acre under changing cost structures. The irrigation costs, i.e. electrical power, labor and the water itself, are generalized so as to reflect the costs incurred by the "average" producer in the Northern Utah area. The potential yield for alfalfa as used in the model was determined from experimental work done in Logan, Utah in 1980 (Hanks and Retta).

CHAPTER II

REVIEW OF LITERATURE

The goal of good irrigation management is to maximize the amount of irrigation that goes to transpiration and minimize the irrigation going into non-transpiration processes (Hanks and Retta). Because of the many interactions between scheduling of irrigation water and crop yield, the design of an irrigation system and its subsequent management have a strong influence on net farm income (Hill and Keller).

Irrigation Scheduling

Pilot projects and research studies (on irrigation scheduling) show, on the average, a saving in water and energy of about 35% (Fischbach). Estimates in 1982 by the Institute of Agriculture and Natural Resources placed the savings in fuel and nitrogen (smaller leaching loss) at $18 an acre for farmers who scheduled using gated pipe and $32 an acre for those using center pivot sprinkler systems. It was also estimated that $2.50 an acre would cover the cost of irrigation scheduling ("Scheduling Catching on in Nebraska", 1982). On 800,000 acres of cropland in Nebraska 5.8 million acre inches were saved by irrigation scheduling in 1977. This amounted to 7.3 inches per acre (Ross 1978a).

Nitrogen fertilizer loss associated with excessive irrigation is estimated at 10-15 pounds per acre-inch of water leaching through the soil (Ross 1978b). While this is of critical importance to nitrogen-using crops like corn and potatoes it was not relevant to this study because alfalfa is a nitrogen producing crop. The two other major nutrient elements, phosphorus and potassium, however are needed by alfalfa to achieve maximum yields in conjuction with irrigation management. Unlike nitrogen, phosphorus and potassium are generally quite immobile and therefore not leachable (James, Hanks and Jurinak).

In a recent experiment four different irrigation scheduling techniques were field tested on corn in a fine textured soil (Fischbach). The scheduling procedures included the following options: (1) crop water use equation, (2) electric resistance blocks, (3) stage of crop growth using the hand "feel" method to determine soil moisture, and (4) 2-3 inches every 14 days minus rainfall (.25 inches peak daily use X 14 days = 3.5 inches). A fifth treatment included no irrigation. No significant difference at the 5 percent level was found in corn grain yields between the different irrigation procedures. There was, however, a significant difference in yield between the irrigated plots and the dry (no irrigation) plot. It was felt that option 2 required the least amount of effort and was the simplest method of scheduling, followed by option 4 and option 3 (they were judged to be equal), with the most difficult method being number 1. It was found that for corn applying 2 or less inches of water at each irrigation (in Fischbach's experiment) was important so that nitrogen, water and/or energy was not wasted.

Previous Yield-Water Use Modeling

There has been a large amount of yield data collected for alfalfa. A linear relationship between yield and ET is very strong (Hanks and Retta). A recent study made at Logan on three alfalfa varieties showed no appreciable difference in yield or ET due to variety (Hanks and Retta).

Much recent interest in yield-water-use relations comes from economists who desire to know the economic viability a given irrigation system (Hanks 1983). A similar experiment to the one herein reported was performed using a modeling technique to predict the effect of irrigation frequency and amount on yield and net return per hectare. It was found that the highest net return, or smallest loss, was for an intermediate irrigation that produced less than the maximum yield. Similar amounts of irrigation water produced different returns because of different irrigation timing (Kanemasu, Stone and Powers). Another modeling experiment to evaluate the economics of irrigation was performed in which the model of Childs and Hanks (1975) was used to predict the economic relations of saline irrigation water. An economic value was put on the relation of irrigation management to the salt content of the drainage water (Andersen and Hanks).

The contribution of this thesis, as it applies to yield-water use modeling, was to analyze the predicted alfalfa yield and accompanying net profit per acre under several different irrigation management options. The options included no irrigation, irrigations every two weeks (eight irrigations), every three weeks (five irrigations) and irrigations scheduled by a computerized soil-water balance equation.

Irrigation Costs

Electrical energy prices for irrigation in some parts of the country are rising so rapidly that scores of irrigators will either reduce their irrigated acres or quit irrigation in the near future (Gardner). In the geographic region served by Utah Power & Light, a privately owned public utility, the cost per unit of power for running a 100 hp pump full time has increased nearly 4 1/2 times from 1974 to 1982 (Andersen).

Along with the increases in energy costs, the cost of water has increased in many parts of the western United States. In the area near Fort Collins, Colorado, for example, the cost of water from the Big Thompson Project has gone from $300 per acre-foot in 1965 to $2,200 per acre-foot in 1980 (Cordova). According to U.S.D.A. economist Marie Leigh, since "cities and energy developers are able to afford three to four times the price farmers are paying for their irrigation water, those water costs will continue rising with the population growth" (Cordova, p. 30).

Economic Concepts

Net Profitability

The economic feasibility of any production process can be determined by examining its net profitability. By this approach, the total production costs are subtracted from gross revenue. Achieving and maintaining the maximum positive net return occurs by either maximizing profits or minimizing costs.

Marginal Analysis

Determining the increase, or decrease, in production with each additional inch of irrigation water for five and eight irrigations required that the marginal physical product (MPP) be calculated. Multiplying the MPP by the price of alfalfa yielded the marginal revenue product, or the increase in net revenue associated with each additional inch of water per irrigation. When the MRP of an input equals its cost (in this case the cost water and application) use of the input should stop since continued use of the input would yield negative marginal returns assuming a constant input cost. The following equations, 2.1 through 2.3, show the marginal relationships:

(2.1) Incremental increase in yield = MPP

(2.2) MPP * Price of alfalfa = MRP

(2.3) Max. Revenue when MRP = Incremetal Cost of water

From the above equations it is evident that a producer should apply only that amount of water which returns a value (as measured in dollars per acre) equal to or greater than the cost of water plus the cost of water application.

CHAPTER III

THEORETICAL MODEL

This chapter describes the plant growth model used in simulating alfalfa production under different irrigation options. The climate data needed and the manipulative methods employed to arrange the data into the format required by the model are outlined. An explanation of the parameters that give the model site specificity is also provided. The model's input and output variables are defined and the specific input coefficients and parameters used in the model are given. Finally, the irrigation options are defined and the specific variables given.

Description of Plantgro

Yield Equation

The Plantgro model written by Hanks (1974) is a computerized simulation which predicts dry matter (and grain) production based on crop water usage. The yield equation is shown below:

$$Y/Ymax = T/Tmax \qquad (3.0)$$

where:
Y = Yield
Ymax = Maximum or Potential Yield
T = Transpiration (Season)
Tmax = Maximum or Potential Transpiration (Season)

Unlike other water use models Plantgro bases the yield calculation on T (transpiration), rather than ET (evapotranspiration), since E (soil evaporation) does not contribute towards plant growth. The contributing part of crop water usage is transpiration, or the amount that the crop uses (transpires) in the growth process.

ET Separation

A unique feature of the Plantgro model is its separation of ET into the two separate components: evaporation from the soil (E) and transpiration from the crop (T). This is a necessary step because Hanks bases the yield equation on transpiration (T) instead of ET. The primary motivation for basing the yield equation on T rather than ET is that the latter is heavily dependent on the climate. Accordingly, Rasmussen and Hanks (1978) state that such annual changes in the relationship of ET to yield are mainly due to variations in E, while the relation of T to yield (or relative yield) is relatively constant.

The model requires some input data manipulation in order to split ET into its two components. The specific alterations will be discussed later in this chapter.

Water Balance Equation

As noted above, calculating ET, primarily T, is essential when predicting yield using water balance equation. The model predicts ET from a 5 layer soil profile based on the following water balance equation:

$$ET = Ir + Rn + Dp - Dr - Ro \qquad (3.1)$$

where
ET = Evapotranspiration
Ir = Irrigation
Rn = Rainfall
Dp = Soil water depletion
Dr = Drainage
Ro = Runoff (assumed zero in this case)

The equation works much like a savings account in which the balance is affected by deposits and withdrawals. The beginning ET balance is zero. Deposits are irrigation, precipitation and soil water depletion with drainage and runoff as the withdrawals. (Even though depletion withdraws soil water it is added to Ir and Rn because it is a component of consumptive use or ET, whereas Dr and Ro are not). Through the iterative process of the model, ET is calculated by keeping track of the amount of water coming into the soil and the amount leaving. Specific seasonal climate factors affect the rate at which the soil water is depleted (Dp) during the growing season. When soil water is limiting due to a lack of irrigation or low precipitation, ET and yield are curtailed.

No further discussion of the model's explicit equations will be given. The interested reader can find additional information in Hanks (1974), Hanks (1983), Retta and Hanks (1980), or Long (1983).

Soil Parameters Needed by Model

Beginning soil moisture (BGSM) was assumed to be at field capacity at the beginning of the season because of snow melt. Field capactity for Millville silt loam was calculated to be 23% by volume or 16.56 inches in the 6 foot soil profile. Wilting point, the level of soil moisture at which a plant cannot extract water fast enough to satisfy transpiration demand was set at 11% volumetric water content. Water holding capacity (WHC) was then calculated by subtracting the wilting point (WILT) from field capacity (FC) which equalled 12%, or 8.64 inches of available water in the soil profile.

The soil profile, or thickness array (THK), was divided into 5 layers for use in the model. The top layer was set at 6 inches, followed by layers of 6, 12, 12, and 36 inches respectively for a total of 6 feet. Also needed by the model was the amount of water beyond wilting point which could be removed from the top six inch soil layer by evaporation. This amount, referred to as airdry moisture content, was set at .7 inch.

Crop Parameters Needed by Plantgro Model

The growing season for alfalfa used in the model was 149 days--April 15 to September 10. An established stand of alfalfa was assumed with an effective root zone of 6 feet. Harvesting dates were June 10, July 24 and September 10. First crop required 57 days of the growing season with second crop taking 44 days and third crop 48. The percentage shares of the growing season were respectively 38%, 30% and 32%. The water stress point for alfalfa was assumed to be .5, which meant that when available soil-water storage (SWS) was less than 50% of available water (WHC) transpiration would be limited (or less than potential) and growth would be slowed.

Plantgro's Climatic Input Requirements

The specific daily weather data collected were high and low temperature, wind movement, pan evaporation and precipitation. However, the only climatic data needed for use in the model were pan evaporation and precipitation. Pan evaporation, or Epan, is the amount of water that evaporates from a "standard" pan placed near or in a field where crops are grown. It is one method of estimating potential evapotranspiration or Eo. Epan is adjusted to a specific site selection by means of a pan coefficient, Kp. The range of the Kp coefficient is from 0.7 to 1.1. In this study the pan coefficient was assumed to be 1, meaning that the daily amount of pan evaporation as recorded at the U.S.U. Experiment Station was the amount of daily potential evapotranspiration used in the Plantgro model. The following equation shows the relationship:

$$Eo = Epan * Kp \tag{3.2}$$

where:
Eo = potential ET
Epan = pan evaporation
Kp = pan coefficient

Climate Data Manipulation

The model also required that potential soil evaporation

(Ep) be separated from potential evapotranspiration (Eo). This required the use of crop coefficients, Kc, which simulate the changing balance between soil evaporation (Ep) and transpiration (Tp) throughout the growing season. As alfalfa begins to grow in the early spring the majority of ET is in the form of soil evaporation, E, since the plant is not effectively shading the soil. As the plant grows ET quickly shifts primarily to transpiration, T, because the soil is almost totally shaded by the plant in addition to the plants increased consumptive water use. Important in determining the changing balance between E and T are crop coefficients, Kc. Equation 3.3 shows how they are used to estimate potential soil evaporation, which is required input data for the Plantgro model.

$$Ep = Eo * Kc \qquad (3.3)$$

where:

Ep = potential soil evaporation
Eo = potential ET
Kc = crop coefficient

The following table shows Kc values for alfalfa at Huntington, Utah as reported by Long (1983). Specific Kc values were not available for the U.S.U. Experiment Station or surrounding area. While the data from Huntington would not be identical to data collected at Logan, the general trends are expected to be similar. The Kc values show the percentage that Ep is of Eo throughout the growing season for each crop.

TABLE 1. Crop Coefficient Values, Kc, for Alfalfa at Huntington, Utah, for Determining Ep as a Percent of Eo.

	Percent of Season Harvest to Harvest									
CROP	10	20	30	40	50	60	70	80	90	100
I	98	70	50	5	5	5	5	5	20	40
II	90	90	70	30	15	15	15	15	15	15
III	98	98	98	90	5	15	15	20[a]	20[a]	40[a]

NOTE: Taken directly from Long (1983).

[a] Adjusted down from Long's data with permission due to probable errors in field measurement.

An example of the Eo, Ep, Kc, and Tp data transformation can be found in Appendix A. For use in the model, both Eo and Ep were 5 day averages. The model used the 5 day average as five daily values. This was necessary because of memory capacity constraints with the microcomputer used. The variance between the seasonal sum of the 5 day averages and the daily Eo and Ep values was never more than three-tenths of an inch.

Summary of Climate Data Input

Rainfall and the day it occurred, along with the 5 day Eo and Ep average, comprised the climatic data needed by the Plantgro model. Sixteen years of climate data--the years 1953-1955 and 1971-1982--were used in the model with each year constituting a "run" with the model. Under this arrangement each irrigation option, including the model-calculated irrigation schedules, were simulated for 16 years. Tables 2 and 3 summarize Plantgro's input/output data.

Summary of Plantgro Input Parameters

TABLE 2. List of Plantgro Input Variables. Adapted from Retta and Hanks (1980) and Long (1983).

Variable name	Definition	Coefficient(s)
DAYS	Days in growing season	149
AIRDRY	Water extractable below wilting point in top layer by evaporation	-0.7
AWFAC	Fraction of SWS/WHC below which T will be less than potential	0.5
RTDAMX	Number of days to maximum rooting depth	1.0
POTPRO	Factor to multiply T/Tp to get yield in desired units	1.0
VARY	Factor to multiply Epan to convert to Eo (pan coeff.)	1.0
OUTPUT	Interval (days) for printout (Arbitrary selection)	10.0
BGSM	Beginning volumetric soil-water content of each layer	.23
THK	Thickness of each soil layer (in inches)	6,6,12,12,36
WHC	Water holding capacity of each layer	.12
WILT	Permanent wilting point of each layer	.11
DDST	Duration of each growth stage in relative days or energy units	.38,.3,.32

Summary of Plantgro Output

TABLE 3. List of Plantgro Output Variables. Adapted from Retta and Hanks (1980) and Long (1983).

Variable name	Definition
DAY	The day of the season
CVAP	Cumulative potential ET (Eo) (cumulative pan evaporation in this study)
TRANS	Cumulative transpiration (T)
SOLEV	Cumulative soil evaporation (E)
CETACT	Cumulative evapotranspiration (E + T)
RAIN	Cumulative rainfall
IRRIG	Cumulative irrigation
DRAIN	Cumulative drainage
DEPL	Soil-water depletion relative to BGSM
SM1,..,SM5	Volumetric soil-water contents of each soil layer
GRAIN	Grain yield relative to potential (not applicable in this study)
DRY MATTER	Dry matter yield relative to potential

Irrigation Options Used in the Simulation

Three irrigation options were chosen for use in the simulation. They were selected in an effort to simulate the "average" irrigation frequency in the Cache Valley area of Utah. The options were then tested against model-generated irrigation schedules in terms of effect on yield and cost effectiveness. Table 4 shows the options.

TABLE 4. Irrigation Options Used in the Simulation.

No. of irrigations	Interval Between Irrigations	Date of First Irrigation
0	None	None
5	3 Weeks	May 25
8	2 Weeks	May 20

Amount of Water Applied

The amount of water applied at each irrigation was the control variable, ranging from 0 to 8 inches. The following table shows the gross irrigation amounts:

TABLE 5. Gross Seasonal Irrigation Amount in Inches.

	Inches per Irrigation							
Option	1	2	3	4	5	6	7	8
			(Total Per acre)					
5 Irrigations	5	10	15	20	25	30	35	40
8 Irrigations	8	16	24	32	40	48	56	64

Description of Irrigation Options

The "no-irrigation" option simulated the producer who is dry-land farming. Alfalfa produced on "dry-farms" represents approximately 30% of the total amount produced in Cache Valley. Five irrigations during the growing season was assumed to be a representative irrigation frequency in the area of the study. Eight irrigations simulated more frequent irrigation.

Duration of Irrigations

The pumping rate, or the amount of water applied during a specifed time period, was set at .3 inches per hour. Table 6 shows the total hours pumped during the season and the length of each irrigation turn based on that pumping rate.

TABLE 6. Length of Irrigation Options - in Hours Per Acre. (Pumping rate of .3 inches/hour).

	Inches per Irrigation							
Option	1	2	3	4	5	6	7	8
				Total Hours				
5 Irrigations	17	33	50	67	83	100	117	133
8 Irrigations	27	53	80	107	133	160	187	213
				Length Per Irrigation Set				
5 Irrigations	3.4	6.6	10	13.4	16.6	20	23.4	26.6
8 Irrigations	3.4	6.6	10	13.4	16.6	20	23.4	26.6

Irrigation Timing

The dates on which water was applied with the 5 irrigation option were May 25, June 18, July 9, August 1 & 22. With 8 irrigations the dates were May 20, June 3 & 18, July 2 & 16, Aug. 1 & 17 & 31.

The irrigation options, including the model-calculated schedules, incorporated a spacing of at least 7 days before and after harvesting where no irrigation could take place. The "front" lag provides time for the soil to dry out before the harvesting equipment was allowed on the field. The "back" lag provides time for the hay to field cure, be baled and hauled off the field.

Irrigation Efficiency

Many factors are included in the overall operation efficiency of any irrigation system. Specific areas where efficiency is measured is in water conveyance, water application, water use, water storage and water distribution (see Appendix C). Individual irrigation systems will have unique efficiency levels. For use in the simulation the various efficiencies were assumed to be one, or 100%, since the absolute level is not the critical factor. The nature of the project was comparative, i.e., comparing fluctuations in yield, drainage, and ET with different irrigation options. Assuming different irrigation efficiency levels would change the absolute magnitude of the output data but would not the change the relative relationships.

Irrigation Schedule Created By Model

The yearly irrigation schedules created by the model were formulated through the iterative use of the water-balance equation 3.1 with the exception that it solved for I (irrigation) instead of ET as shown in equation 3.4.

$$I = ET + Dr + Dp - Rn - Ro \qquad (3.4)$$

where:

I = Irrigation
ET = Evapotranspiration
Dr = Drainage
Dp = Soil Water Depletion
Rn = Precipitation
Ro = Runoff

The boundary condition for this equation was 50% of available water remaining in the soil profile at irrigation. The model initiated an irrigation, based on equation 3.4, when available soil water in the profile was less than 50% of potential water holding capacity. Three exceptions to this were one week before and after each harvesting date. As the crop would go without an irrigation for 14 days, the available soil water (as a percentage of WHC) needed to above 87% one week prior to first cut, 94% one week before second and 66% one week before third cut to avoil crop stress (going below 50% available water) during the 14 day dry (no irrigation) period. If available water was below the proper amount an irrigation was initiated to bring the soil moisture up to the required level. The variation in the required amount reflects the fluctuating water demand by the crop in conjunction with climatic changes. The specific amount of soil moisture needed was determined from 25-year average daily pan evaporation data.

The timeliness of irrigation avoided any severe crop water stress. The application of water at each irrigation was terminated when the amount needed to refill the soil profile was reached, thus eliminating drainage or runoff.

The model created each schedule based on the same climate data as the other irrigation options. The number of irrigations during the season and the amount applied at each irrigation were the variables dependent on each unique set of seasonal weather data.

CHAPTER IV

RESULTS FROM THE MODEL SIMULATION

Type of Irrigation System

Several different irrigation systems were simulated under the different irrigation cost scenarios--hand moved lines, surface (flood) irrigation and wheel lines. In some cases the costs of surface irrigation may be similar to sprinkler irrigation, or even higher under good water and furrow management. The cost of using wheel lines may also be similar to the cost of moved handlines with a possible difference in the labor expense. The cost of using center pivot irrigation was not included since very few, if any, exist in the Cache Valley area of Utah.

Results of the Simulation

The alternative simulation model "runs" included comparison of various factors of production for different irrigation options. As previously mentioned these irrigation options included no irrigation, 5 irrigations, 8 irrigations and a schedule of irrigations determined by the model (irrigation scheduling). These "factors" of production included gross and net irrigation water applied, drainage, yield, seasonal precipitation, ET and T (transpiration) as separate entities, and water application efficiency. These elements may be thought of as the technical aspects of the modeling. In addition, pan evaporation was graphically compared with ET under the four different irrigation options. The graphs with inches per irrigation on the the X axis represent 16 year averaged data.

Gross Irrigation Water Applied

Figure 1 graphically presents the gross amount of irrigation water applied under each of the different irrigation options. Gross amount is defined as the amount of water pumped onto the field, not including precipitation or available soil-water. Obviously, the no irrigation option cannot be graphed.

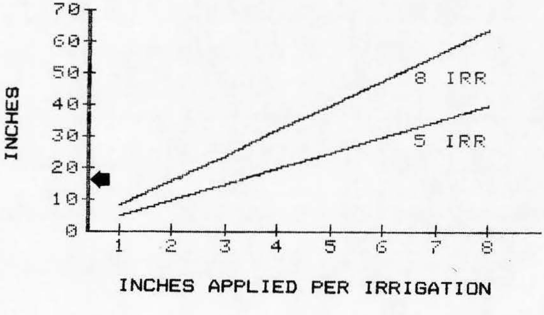

Figure 1. Gross Water Applied Related to Irrigation Frequency and Amount of Water Applied at Each Irrigation. (➡ denotes model-calculated irrigation schedule average amount).

The seasonal average amount of water applied by the model, as noted by the arrow, was 16.80 inches.

Number of Irrigations & Amount Applied by the Model

Figure 2 presents the yearly fluctuations in both the amount of irrigation water applied and the number of irrigations under the model-scheduled irrigations.

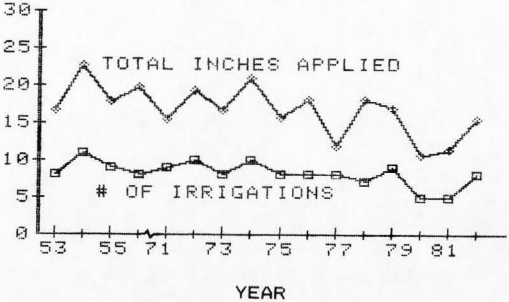

Figure 2. Yearly Fluctuations in Gross Irrigation Amount and Number of Irrigations as Determined by the Model.

The average number of irrigations was 8 (rounded down to an integer from 8.2). The high was 11 irrigations in 1954, while the low of 5 was achieved in 1980 and 1981. Note the correlation between the amount of irrigation water and the number of irrigations (roughly two inches applied per irrigation). The standard deviation from the 8 irrigation mean was 1.6. The mean amount of water applied was 16.8 inches with a high of 22.6" in 1954 and a low of 10.8" in 1980. The standard deviation from 16.8" over the 16 year period modeled was 3.3".

Irrigation Drainage

Drainage of irrigation was essentially linear (Fig. 3). This is a result of additional increments of irrigation water going entirely to drainage once the water holding capacity of the soil had been achieved. In addition to irrigation, both the amount and frequency of precipitation had an effect on drainage. Small amounts of water were lost to drainage under the no-irrigation option because of heavy or closely space rainstorms. For that reason, drainage in Figure 3 reflects only that amount attributable to irrigation water, (total drainage - drainage with no irrigation = irrigation drainage).

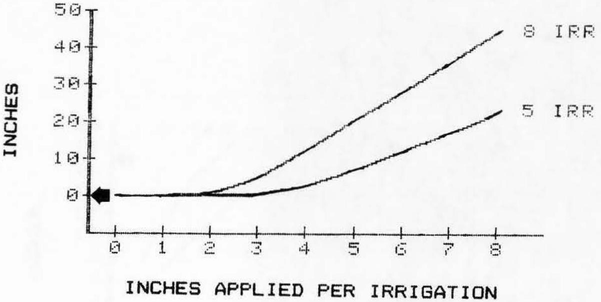

Figure 3. Irrigation Water Lost as Drainage by Increasing the Inches Applied per Irrigation.

Five irrigations showed minimal drainage up to 4 inches per irrigation. However, after that point any additional water per irrigation went entirely to drainage. For eight irrigations any water applied beyond 3 inches per irrigation was essentially wasted. The model-calculated irrigation schedules kept drainage essentially at zero, as noted by the arrow.

Net Irrigation

Net irrigation is the amount of water applied which is stored in the root zone and is available for the crop consumption. This amount refers to the amount of water not lost through either drainage or runoff. Simply subtracting the amount of irrigation drainage from the gross amount of water applied yields net water storage in the soil profile. Figure 4 shows the differences in the amount of net irrigation among the three options.

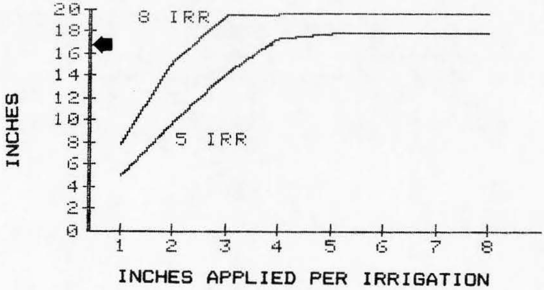

Figure 4. Net Water Applied under Different Irrigation Options.

It is interesting to note that net irrigation water is maximized with eight irrigations followed by five irrigations and the model. Maximizing net irrigation, however, is not necessarily the goal of irrigation management. It is more important to achieve maximum transpiration. Seasonal net water applied with five irrigations topped out at 17.8", eight irrigations at 19.7" and the model at 16.8", as noted by the arrow. It is important to note that net and gross water application were equal under the model-calculated schedules since drainage was kept at zero.

Yield Comparison

Yield comparison, Figure 5, correlates well with several graphs already presented. The points at which maximum yield is achieved with five and eight irrigations relate directly to the points where net irrigation is maximized as seen in Figure 4. Conversly, drainage increases by the amount of the additional water applied when yield is at the maximum point as shown by comparing Figures 3 and 5. Yield is defined as alfalfa tonnage.

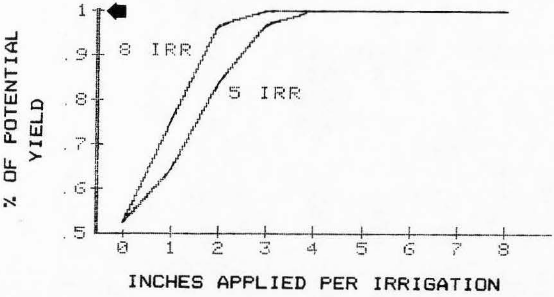

Figure 5. Alfalfa Yield as a Percentage of Potential Under Different Irrigation Options.

The mean and standard deviation under irrigation scheduling was 99% + or - 1% potential yield. Dry matter yield with no irrigation, as shown in Figure 6, had a significant variation from year to year. The 16 year average yield was 52% of potential (obtainable yield under optimal irrigation management). The highest estimated yield during the 16 year period with no irrigation was 69% of potential, with a low of 35% and a standard deviation of 10%. The Plantgro model does not show a yield reduction at irrigation levels of over 30 inches applied during the season. In reality, it is possible that alfalfa yield would be reduced at high levels of water application (over-irrigation) due to water logging the soil.

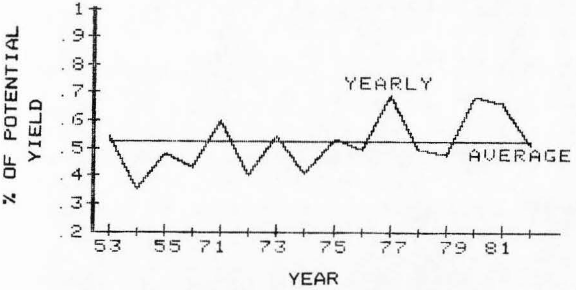

Figure 6. Yield Average and Yearly Fluctuation With No Irrigation.

Seasonal Precipitation

The average rainfall, as shown in Figure 7, for the 149 day growing season was 6.3 inches with a standard deviation of 2.5". The high amount was 10.3" and occurred twice while the low amount was 2.4 inches. As would be expected, there was a very close relationship between the amount of rainfall and yield with zero irrigation. There also exists an inverse relationship between seasonal precipitation and the amount of water applied by the model-calculated irrigations schedules. This can be seen by comparing Figures 2 and 7.

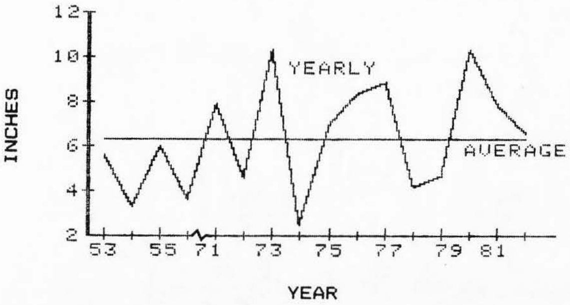

Figure 7. Seasonal Precipitation from April 15 to September 10 for U.S.U. Greenville Experiment Farm.

ET Comparisons

Figure 8 shows the comparative relationship of ET among all the irrigation options. As can be seen, ET was maximized by the model. Figure 9 shows the yearly ET variation for the model-calculated irrigation schedules. Figure 10 graphically depicts the variation in ET with zero irrigation. The correlation between seasonal ET and precipitation under zero irrigation is much like the previously noted yield-seasonal precipitation relationship for no irrigation. The effect of precipitation on ET is minimal under the other irrigation options.

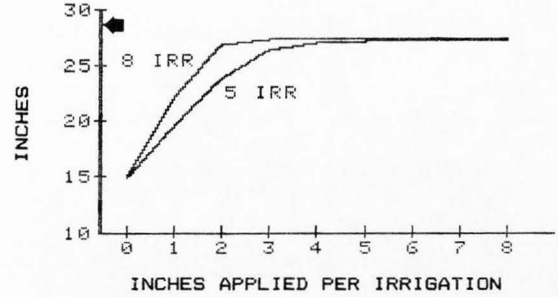

Figure 8. ET Comparison for All Irrigation Options.

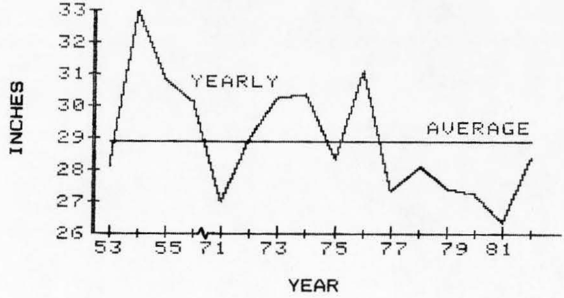

Figure 9. ET for Model-Calculated Irrigations.

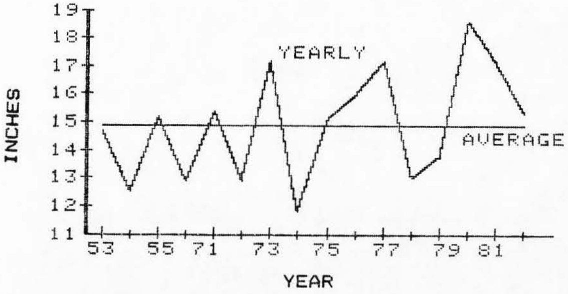

Figure 10. ET with No Irrigation.

ET under no irrigation averaged 15 inches, with a high of 18.7", a low of 11.7" and a standard deviation of 2". The model irrigations had an average ET of 28.9, a standard deviation of 1.8" with a high of 33" and a low of 26.3". It is interesting, yet not surprising, to note the relationship between ET and yield under zero, five and eight irrigations. Increases in ET are matched by almost identical increases in yield (in relative terms) and when ET is maximized, yield is also. (Compare Figure 5 with Figure 8, and Figure 6 with Figure 10).

Transpiration

Transpiration was similar to ET in its graphical shape. It was shown that five and eight irrigations achieved a slightly higher level of T than the model schedules. Figure 11 shows the predicted T for all the irrigation options while Figure 12 shows the flucuations in T with the model-calculated irrigation schedules.

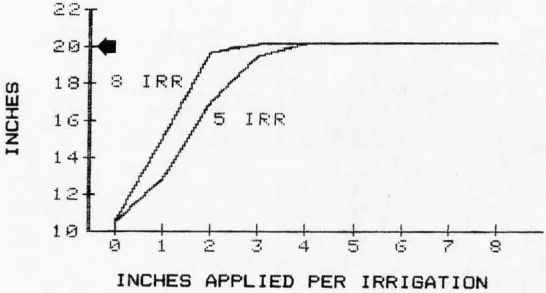

Figure 11. Predicted Transpiration for All Irrigation Options.

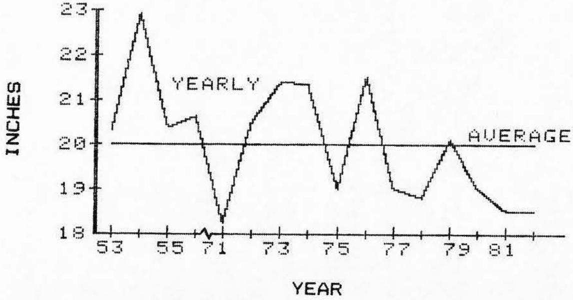

Figure 12. Seasonal Fluctuations in Transpiration for Model Calculated Irrigations.

For the model, average T was 20 inches with a standard deviation of 1.4". The high was 22.9" and low 18.2". No irrigation, shown at zero inches per irrigation on the graph, had an average T of 10.4 inches, a deviation of 1.6", with a high of 13.3" and a low of 8.2".

Water Application Efficiency

Water application efficiency measures how much of the water applied to the soil is retained. Inasmuch as different irrigation options were tested this measure becomes important. As was previously mentioned, there are many factors which contribute to the overall efficiency of an irrigation system, water application is one of them. The reason it is being included is because it was measurable in the modeling process. The calculation is based on the following formula:

$$\text{Ewa} = 100\ (\text{Ws} / \text{Wd}) \tag{4.1}$$

where:
Ewa = Water application efficiency
Ws = Water stored in the soil (root zone)
Wd = Water delivered to the field

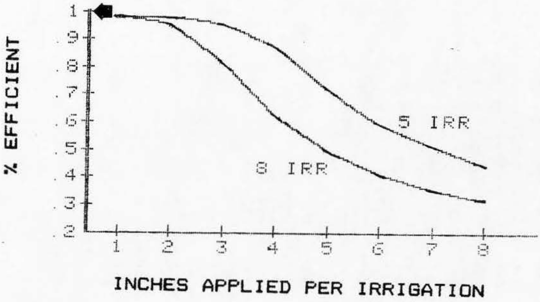

Figure 13. Water Application Efficiency Comparison for Each Irrigation Option.

Pan Evaporation

Pan evaporation (Epan) was used as the amount of potential evapotranspiration (Eo) in the simulation. Eo could theoretically equal Epan if water was never limiting in the soil profile and the crop coefficient (Kc) never exceeded one. In reality this is very difficult to achieve as there are periods of time when water cannot be applied to the crop because of harvesting procedures. Figure 14 presents a comparison of how close actual ET (as estimated by the model) came to pan evaporation, which is potential ET (Eo). This measure is actually quite useful in helping alfalfa producers determine the proper timing and correct amount of water to apply at each irrigation if, in fact, actual ET is less than pan evaporation. This assumes farmers base their calculations on how much and when to irrigate from pan evaporation data. In other words, if ET in the field is some estimated percentage of pan evaporation, and if pan evaporation can be determined (newspaper, radio or on-farm pan) then actual ET can be estimated. Estimating daily ET is critical for irrigation scheduling using a soil-water balance equation.

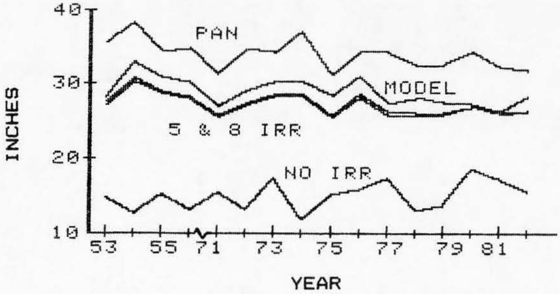

Figure 14. Pan Evaporation as Compared with Calculated ET for the Different Irrigation Options.

Pan evaporation at the U.S.U. Experiment Station, for the years included in this study, average 33.9" with a high of 38.1" , a low of 31.3" and a standard deviation of 1.9". Five and eight irrigations were graphed at the "inch per irrigation" level where ET was initially maximized (refer to Figure 8). With five irrigations the maximum ET level was first reached at 5 inches per irrigation (any additional irrigation going totally to drainage) and had a mean of 27.13", with a high of 30.4" and a low of 25.5". Maximum ET for eight irrigations was reached at 3 inches per irrigation, with a mean of 27.4", a high of 30.7" and a low of 25.7". Both options, five and eight irrigations, had standard deviations of 1.4". Table 8 summarizes the ET and pan evaporation comparison:

TABLE 7. Pan Evaporation and Simulated ET Over 16 Year Period at Logan, Utah.

Option	High	Low	Mean	Standard deviation
		Inches		
Pan evaporation	38.1	31.3	33.9	1.9
		Inches ET		
No irrigation	18.7	11.7	15.0	2.0
5 irrigations	30.4	25.5	27.13	1.4
8 irrigations	30.7	25.7	27.4	1.4
Model-schedules	33.0	26.3	28.9	1.8

ET as a Percentage of Epan

It was found in the simulation process that for the model-calculated irrigation schedules, seasonal ET was 85% of Epan. Therefore, in the Logan, Utah area, the necessary amount of water needed by alfalfa is 15% less than the amount of pan evaporation. For five and eight irrigations ET was estimated at 80% of pan evaporation. These figures implicitly assume normal seasonal climatic conditions (high and low temperature, wind movement, solar radiation, among others). Use of these figures in calculating ET and irrigation amounts based on pan evaporation should be done with discretion and in conjunction with some other method of soil water monitoring to assure proper irrigation.

CHAPTER V

ECONOMIC ANALYSIS OF THE DIFFERENT IRRIGATION OPTIONS

Irrigation Costs

Definition of Costs

The irrigation costs used in the economic model were water, power and labor expense. The specific cost figures chosen for use in the model are representative of average irrigation expenses only. They are not intended to represent specific costs of any particular producer. For this reason the data derived from the cost analysis are for comparative use only and should not to be used as actual irrigation costs of a specific farm or field.

Water Cost

The first expense considered in the model was the cost of irrigation water. Several elements comprise the cost of irrigation water. They include the water itself, canal maintainence, water master fees and others. No effort was made to delineate the exact costs in this study since these type of costs are generally site specific. The selected water costs for use in the economic model were $20, $5, and $0 per acre foot. Quality of water, i.e. salt content, was not considered in this study in terms of its effect on production or costs. Study of irrigation water quality on predicted crop yield was beyond the scope of this thesis.

Power Cost

The power costs associated with irrigation are for pumping water. Water is pumped from a variety of sources including wells, canals, ponds, streams and rivers. Water pumps can be powered by electricity or pumping engines.

The pumping method chosen for use in the model was electrical, therefore the only cost of pumping was electricity. The costs of electricity were put in a simplified form of \$.50 per hour per acre and \$1.00 per hour/acre. In addition, pumping with no power cost was also included to simulate those producers who have a gravity-powered irrigation system.

Gravity flow irrigation negates the need to pump water since gravity is the energy source, hence it is a very inexpensive method of applying water. This type of system exists in Cache Valley, hence it was included as one of the options. The costs of pump maintainence were not explicitly included in the electrical power cost. An explanation for this ommision will follow.

Labor Cost

The labor expense commonly associated with sprinkler irrigation is for moving pipe (handlines). For surface irrigation the cost of labor is associated with tending the ditches and furrows. The specific labor cost was set at \$2.00 per acre per irrigation assuming a wage rate of \$5.00 per hour.

Cost of Irrigation Scheduling

The cost of scheduling was set at $2.50 per acre per season. The cost will vary, perhaps substantially, based on the irrigation scheduling method employed. Some irrigation scheduling methods may have substantial installation costs, i.e. digging nuetron probe access tubes or installing electrical resistance blocks in the soil.

Alternative Irrigation Cost Structures

The irrigation costs were combined to produce nine different cost structures. The cost of labor was held constant at $2.00 per acre per irrigation with the costs of power and water variable. The various cost options are shown below in Table 7.

TABLE 8. Alternative Irrigation Cost Structures.

	Option								
Expense:	1	2	3	4	5	6	7	8	9
					$/acre				
Labor per irrigation	2	2	2	2	2	2	2	2	2
Power per hour	0	.5	1	0	.5	1	0	.5	1
Water per acre/foot	0	0	0	5	5	5	20	20	20

Scheduling vs. 5 and 8 Irrigations

From a practical production point of view, irrigation scheduling appears to be a superior overall method of irrigating. It has been shown that with irrigation scheduling water is conserved while at the same time achieving potential, or near potential, yields. In addition, the negative effects of excess irrigation are avoided by scheduling irrigations. Water application efficiency is also very high with the model-schedules, as is water storage efficiency since only the water needed to fill the soil profile was provided each irrigation. In addition, irrigation scheduling achieved the highest ET level of the options examined and a comparable level of transpiration (see Figures 8 and 11).

Economic Feasibility of Irrigation Scheduling

Despite its apparent technical superiority, irrigation scheduling has no practical advantage over conventional habits of irrigating unless it is also economically superior. Irrigation scheduling requires an investment of time and money. The net profitability per acre obtained by irrigation scheduling is compared against the net profitability using "conventional irrigation methods" (zero, five and eight irrigations per season) under nine different cost structures. The specific irrigation costs will then be presented for each irrigation option under cost option five, followed by the results of the marginal analysis.

Price of Alfalfa and Potential Yield

Important in the net profitability analysis are two exogenous parameters, the price received for alfalfa hay and the potential yield. For use in the economic model, alfalfa was valued at $80.00 with a potential yield of 7 tons/acre.

Economic Analysis

The "net" profitability of each irrigation option under different input cost structures are shown in Figures 15 through 23. The term "net" requires some clarification. Only variable irrigation costs (water, power, labor) were deducted from total revenue (tons of alfalfa multiplied by price). Important production costs that were neglected included crop establishment (cost of seed, fertilizer), cost of machinery (purchase and maintainence), cost of capital (interest expense for production loan), harvesting costs (twine, labor, gas, oil, grease, hauling, and others), fixed costs (land taxes, rent) and irrigation system maintainence.

The justification for ignoring many of the production costs was based both on the comparative nature and generality of the project. The main emphasis was to test the effect of irrigation scheduling on production variables (yield, drainage, ET, etc.) and net profitability against common, albeit less sophisticated, irrigation methods. The non-irrigation fixed and variable production costs would be the same for the different options at equivalent yields, therefore the only production costs that are pertinent in the comparitive analysis are variable irrigation costs. Subtracting all the production expenses would indeed give a more accurate estimate of "bottom-line" net profit, yet would not change the comparitive economic relationships between the different irrigation options. In other words, the graphs showing net profitability would be lower on the Y axis if all the production costs were included. The relative shape and slope of the curves, however, would remain the same.

The second reason for omitting the major part of the production expenses was to reduce the research data requirement. Many enterprise budgets for alfalfa have already been assembled for specific areas and are a more reliable source of cost estimates. Generalized estimates of production costs are meaningless to individual producers.

Net Profitability With Cost Options 1-3

Reference to Table 7 will be helpful in reviewing the different irrigation cost structures. Figures 15, 16 and 17 show the comparitive net profitability per acre between the four different irrigation options (zero, five, eight and model-schedules irrigations) with water at no cost, labor at a constant level of $2, and power varying from 0, $.5 and $1 per pumping hour. Figure 15 represents a gravity flow irrigation system with a non-fee water source.

The model-calculated irrigations did not apply a fixed amount of water per irrigation, nor was the amount per irrigation a controlled (exogenous) variable. An arrow is therefore used to show net profit for the model-schedules since it cannot be graphed against variable inches per irrigation on the X axis. The graphed data are 16 year averages.

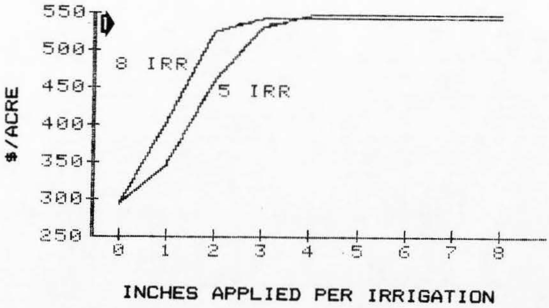

Figure 15. Net Profitability Per Acre Under Cost Option One (Water @ $0/ac.ft., Power @ $0/hr).

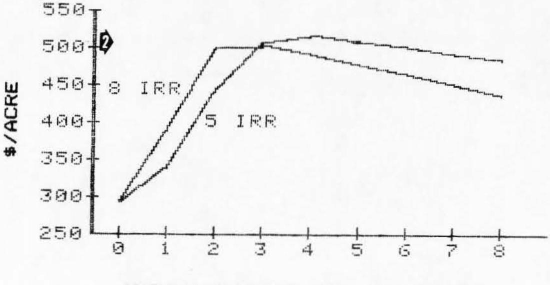

Figure 16. Net Profitability Per Acre Under Cost Option Two (Water @ $0/ac.ft., Power @ $.50/hr).

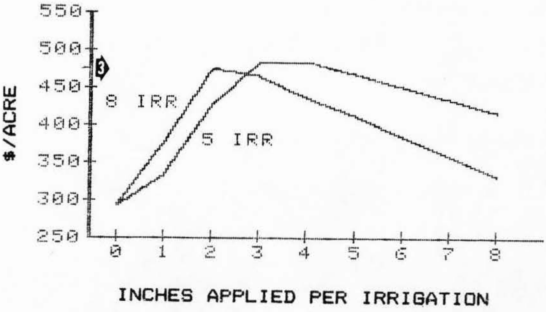

Figure 17. Net Profitability Per Acre Under Cost Option Three (Water @ $0/ac.ft., Power @ $1.00/hr).

Net Profitablility With Cost Options 4-6

In cost options four through six, as shown in Figures 18 through 20, the cost of water increases to $5 per acre foot, with labor a $2 per irrigation per acre, and power varying from 0 to $.50 to $1.00 per pumping hour. Cost option four (Figure 18) simulates gravity flow, but water is no longer free. This is sometimes the cost scenario for an irrigator who obtains water from an uphill canal and pumps using gravity as the power source.

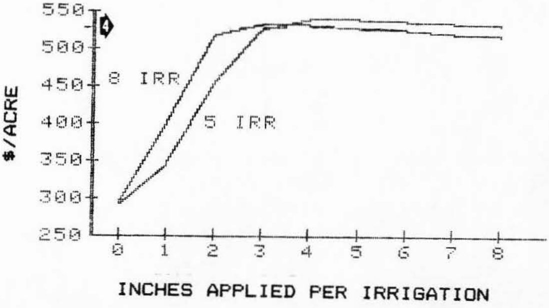

Figure 18. Net Profitability Per Acre Under Cost Option Four (Water @ \$5/ac.ft., Power @ \$0/hr).

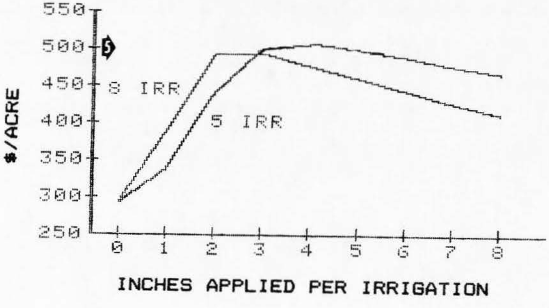

Figure 19. Net Profitability Per Acre Under Cost Option Five (Water @ \$5/ac.ft., Power @ \$.50/hr).

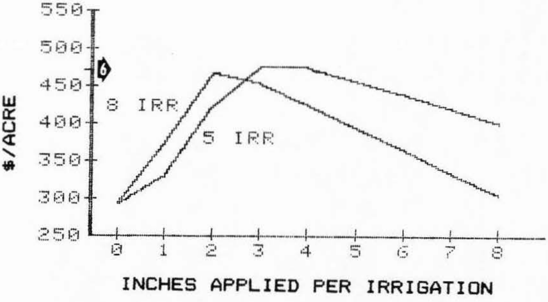

Figure 20. Net Profitability Per Acre Under Cost Option Six (Water @ $5/ac.ft., Power @ $1.00/hr).

Net Profitability With Cost Options 7-9

In Figures 21, 22 and 23 the cost of water moves to $20 per acre foot, labor cost remains at $2, and the cost of power varies from 0 to $.50 to \$1.

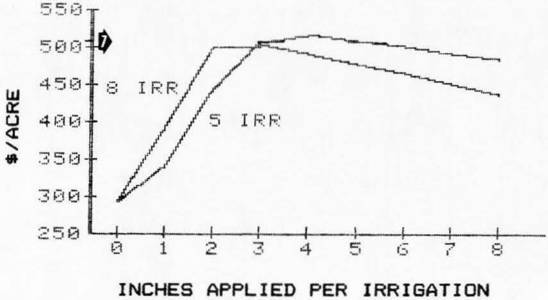

Figure 21. Net Profitability Per Acre Under Cost Option Seven (Water @ $20/ac.ft., Power @ $0/hr).

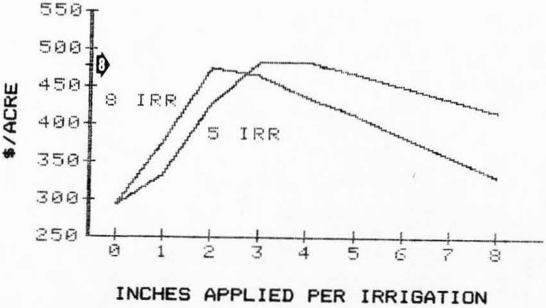

Figure 22. Net Profitability Per Acre Under Cost Option Eight (Water @ $20/ac.ft., Power @ $.50/hr).

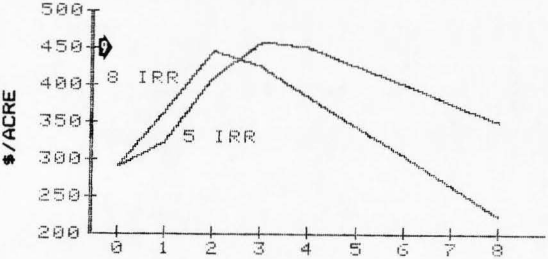

Figure 23. Net Profitability Per Acre Under Cost Option Nine (Water @ $20/ac.ft., Power @ $1.00/hr).

Analysis of Irrigation Costs

Several production options were simulated through the different irrigation cost options (structures). Option one (refer to Table 8, p. 46) represents gravity-flow irrigation from a free water source, such as an uphill collecting pond. Options four and seven also represent gravity flow but with a cost assessment for irrigation water. The other cost options represented various pumping rates and water charges for sprinkler or furrow irrigation systems. Cost option five will be further analyzed as it was viewed as being representative of irrigation costs in the Cache Valley area.

Irrigation Costs

Table 9 contains the data graphically presented in Figure 19. The methods of calculating the various components of total irrigation cost, gross revenue and net revenue are presented for cost option five.

TABLE 9. Irrigation Cost and Revenue Analysis under Cost Option Five.

Labor @ $2.00/irr.
Water @ $5.00/ac.ft.
Power @ $.50/hr.
Potential Yield - 7 tons
Price of alfalfa - $80/ton
Cost of Irrigation Scheduling - $2.50/acre/season

Inches per Irrig.	Labor Cost	Water Cost	Power Cost	Total Irrig. Cost	Yield	REVENUE	
						Gross	Net
<----------------0 Irrigations---------------->							
0	0	0	0	0	.52	291	291
<----------------5 Irrigations---------------->							
1	10	2	8	20	.64	358	338
2	10	4	17	31	.84	470	439
3	10	6	25	41	.97	543	502
4	10	8	34	52	1.0	560	508
5	10	10	42	62	1.0	560	498
6	10	12	50	72	1.0	560	488
7	10	14	58	82	1.0	560	478
8	10	16	66	92	1.0	560	468
<----------------8 Irrigations---------------->							
1	16	3	13	33	.75	420	387
2	16	7	27	50	.97	543	493
3	16	10	40	66	1.0	560	494
4	16	13	53	82	1.0	560	478
5	16	17	67	100	1.0	560	460
6	16	20	80	116	1.0	560	444
7	16	23	93	132	1.0	560	428
8	16	27	107	150	1.0	560	410
<-------------Scheduled Irrigations------------->							
	18.5[a]	7	28	51	.99	552	498

NOTE: Data are 16 year averages, 1953-56,71-82.

[a] Includes the cost of irrigation scheduling.

The data presented in Table 9 together with the graphical depiction of the same in Figure 19 illustrate the effect of irrigation scheduling in comparison with zero, five and eight irrigations. It is evident that irrigation scheduling, on the average, saves both water and money if more than five inches of water is applied each irrigation with five irrigations and if more than three inches is applied under eight irrigations. The same does not hold for cost options one and four where there is no power cost for pumping. Conversely, with higher water and power costs, (cost options six and nine), five and eight irrigations could not profitably pump more than 4 and 2 inches, respectively, per irrigation.

Table 10 shows the 16 year average and total net profit for five and eight irrigations at inch-per-irrigation levels which applied a similar seasonal amount of water as the model-calculated irrigation schedules. Total net profit from zero irrigations is also included. The net profits are based on cost option five. It is assumed that during the 16 year period production costs and the price of alfalfa remained constant. The prices are in nominal terms, having not been adjusted to inflation during the 16 year period. Yearly net profit with five irrigations at four and five inches per irrigation is constant, or nearly so, because potential yield had been achieved. The same holds true for eight irrigations at three inches per irrigation.

TABLE 10. Yearly Net Profit at Optimal Irrigation Levels Under Cost Option Five.

Year	Irrigation Scheduling	5 Irrigations			8 Irrigations		No Irrig.
Inch/Irr		3"	4"	5"	2"	3"	0
Season	16.8"[a]	15"	20"	25"	16"	24"	0
				Dollars/Acre			
1953	500	494	508	497	492	494	304
1954	477	430	494	494	428	493	195
1955	492	506	508	497	506	494	270
1956	489	482	508	497	481	494	242
1971	503	518	508	497	510	494	338
1972	489	492	507	497	484	494	226
1973	502	518	508	497	509	494	302
1974	484	453	504	497	451	494	227
1975	499	518	508	497	511	494	298
1976	497	507	508	497	507	494	272
1977	509	515	508	497	510	494	387
1978	493	507	508	497	505	494	272
1979	501	516	508	497	510	494	264
1980	519	516	508	497	510	494	383
1981	513	513	508	497	508	494	368
1982	503	519	508	497	511	494	284
Average	498	500	507	497	496	494	290
Total	7970	8004	8109	7949	7933	7903	4632
Difference from Model		34	139	-55	-37	-67	-3372

---

[a] 16 year average.

From the preceding graphs (Figures 15 through 23) and from Table 9 it can be observed that under-irrigation, defined as placing the crop under water stress once or more during the growing season, can significantly lower net profitability. The same holds true for over-irrigation, or that point at which large portions of any additional irrigation water drain off or through the soil. Net profits are much less than potential when insufficient or excess water is applied to alfalfa. The data also suggests that conventional methods of irrigation (fixed time intervals between irrigations) can equal, or exceed, the net profitability achieved with irrigation scheduling, assuming the proper amount of water is applied each irrigation.

Distribution of Irrigation Costs

The optimal irrigation level with five irrigations was most often found to be 4 inches per irrigation while with eight irrigations the highest net return was generally reached at 2 inches each irrigation. At these optimal irrigation levels, what are the percentages of each cost component (labor, water and power) of the total irrigation expense? Figures 24, 25 and 26 show the breakdown, by percentage, of the total variable irrigation costs for all of the irrigation options, except for zero irrigations, under cost option five.

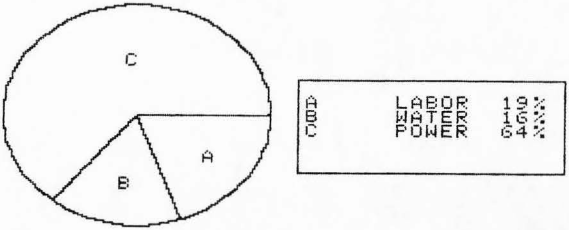

Figure 24. Variable Cost Breakdown, Per Acre, for Five Irrigations at 4" per Irrigation Under Cost Option Five.

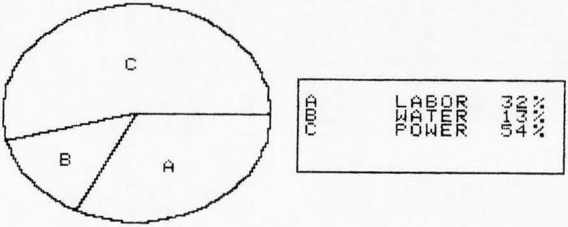

Figure 25. Variable Cost Breakdown, Per Acre, for Eight Irrigations at 2" per Irrigation Under Cost Option Five.

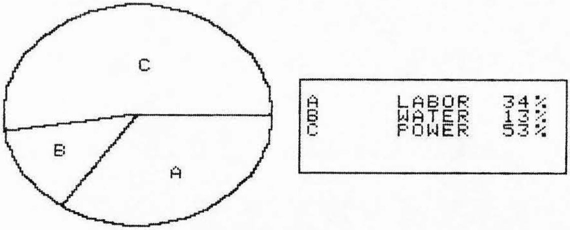

Figure 26. Variable Cost Breakdown, Per Acre, for Model Irrigations Under Cost Option Five.

Irrigation variable cost analysis is helpful in selecting the most economical irrigation system. Irrigators facing high labor expenses can minimize costs by selecting a system that uses a minimal amount of labor, like five irrigations (Figure 24). Conversely, irrigators who are required to pump water at high electricity rates may want to consider irrigation scheduling to reduce their power bill (Figure 26). In short, irrigation system selection should be based on the input cost structure facing the irrigator. To achieve the most cost efficient irrigation system, the least expensive input (labor, power or water) should comprise the largest percentage of total cost.

Economic Marginal Analysis

Marginal analysis is also a helpful tool in most any decision making process. The fundamental concept of marginal analysis is to examine incremental changes in a production process and to measure their economic impact. The model schedules did not lend themselves to marginal analysis since there were no exogenous production variables. The model "created" optimal irrigation schedules, hence all the variables, with the exception of costs (which are not production variables), were endogenous. With five and eight irrigations the amount of water applied at each irrigation was incrementally increased, hence was an exogenous variable.

Marginal Physical Product

The impact on yield, or marginal physical product (MPP), of each additional increment of irrigation water is of great importance in marginal analysis. Figure 27 shows the relationship between yield and additional increments of water for five and eight irrigations. Recall that each additional inch per irrigation under five irrigations equals 5 more inches of total water applied over the growing season, while with eight irrigations the amount is 8 inches.

At zero irrigation predicted yield was 52% of potential or 3.64 tons per acre. At one inch per irrigation estimated yield was .64 for five irrigations and .75 for eight, or 4.48 and 5.25 tons per acre respectively. The marginal increase from zero to one inch is therefore .84 tons/acre for five irrigations and 1.61 tons/acre with eight irrigations. Figure 27 simply shows by how much yield increases by incrementally increasing irrigation.

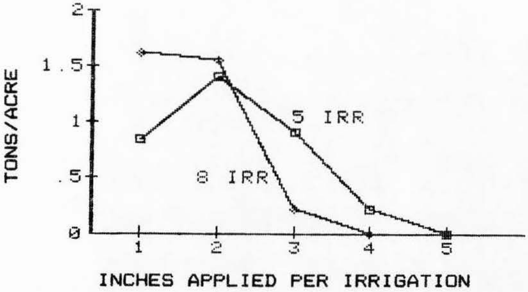

Figure 27. Marginal Physical Product of Irrigation for Five and Eight Irrigations.

Marginal Revenue Product

The marginal revenue product (MRP), or value of the marginal product, is obtained by multiplying the price by the MPP. Marginal revenue (MR) is used interchangably with MRP and is calculated by measuring the change in total revenue given changes in production inputs. Figures 28 and 29 plot the marginal revenue product of irrigation (the increase in total revenue with an incremental increase in irrigation) against the cost of the incremental increase in irrigation (cost of water plus the cost to apply it) for five and eight irrigations respectively. Irrigation cost option five is used for both graphs. The marginal cost of water is not cumulative. It is a measure of the increase in cost from one point of production to the next.

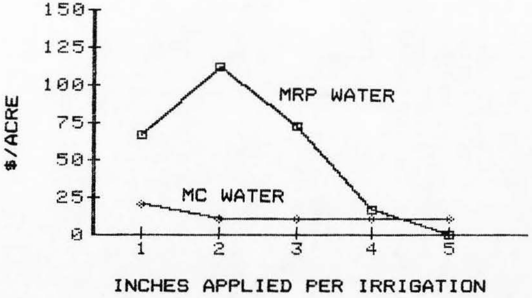

Figure 28. Marginal Revenue Product Plotted Against Marginal Cost of Water and Application for Five Irrigations Under Cost Option Five.

Figure 28 shows the point at which the value of additional water (as measured by increased yield * price) equals its cost. Production beyond the point at which the lines cross would be unprofitable. An implicit assumption is made regarding the demand for alfalfa hay in the marginal analysis. The assumption is that increases in yield, hence increases in the supply, will not lower the market price.

In other words, a horizontal demand curve is implied.

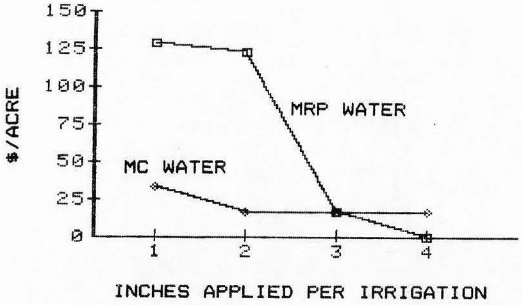

Figure 29. Marginal Revenue Product Plotted Against Marginal Cost of Water and Application for Eight Irrigations Under Cost Option Five.

It is interesting to note the relationship between Figures 28 & 29 and Figure 19. The marginal analysis shows the point at which net profit begins to fall after reaching its maximum point. For this reason it is very useful as a method of determining the amount of inputs to needed to achieve maximum profit.

CHAPTER VI

SUMMARY

Objectives of Study

The major objective of this study was to determine the economic characteristics of irrigation scheduling on alfalfa production in comparison with common irrigation practices. The production variables (yield, drainage, etc.) for the different irrigation options were simulated through the use of a plant growth model. Costs were then associated with the production processes and the net profitability of each irrigation option was evaluated over nine different cost structures.

Results of the Study

Irrigation scheduling was found to be a superior method of irrigation management, from strictly a production aspect, because it is responsive to fluctuations in climate, hence crop water demand. Water lost to drainage was minimized, even eliminated, while potential yield was obtained with the minumum required amount of irrigation water. Seasonal evapotranspiration was higher with irrigation scheduling than with the other irrigation methods. The efficiency of water application was much higher with scheduling since only the amount of water needed to refill the soil profile was applied at each irrigation.

From an economic perspective, irrigation scheduling, on the average, was not clearly superior to conventional methods of irrigating at fixed time intervals, as was seen in Table 10. It was found that five irrigations per season applying four inches each time always averaged a higher net profit than with irrigation scheduling. In many cases a higher net profit was achieved at three inches per irrigation also. With eight irrigations, applying two inches each time, the average net profit equaled or was just under the irrigation scheduling net profit. The various cost options determined the net profit relationship among the different irrigation options.

Irrigation scheduling was superior from an economic perspective when compared with zero, five and eight irrigations at high and low amounts of irrigation. Five irrigations, when compared with irrigation scheduling, always netted a lower profit if less than two inches were applied at each irrigation or if more than five inches were applied (except in cost options 1 and 4). Eight irrigations were less profitable than irrigation scheduling when more than three, and in some cases two, inches were applied per irrigation. In no case did eight irrigations produce a higher net return when less than two inches were applied at each irrigation.

A comparison of the net profitability for the different irrigation options at each incremental inch level of irrigation is presented in following table. The model schedules net profitability is the base against which the other irrigation options are being compared.

TABLE 11. Net Profit Comparison For Zero, Five and Eight Irrigations Against Irrigation Scheduling While Varying the Inches Applied per Irrigation.

Irrigation Option	Compared Against Net Profit With Irrigation Scheduling
No irrigations	lower
Five irrigations	
0 to 3 inches	lower
3 to 4 inches	equal or higher
5 inches	generally equal or lower
5 to 8 inches	lower (a)
Eight irrigations	
0 to 2 inches	lower
2 to 3 inches	equal or lower
3 to 8 inches	lower (a)

[a] Except for cost options 1 and 4.

Summary

The following points can be drawn from this research:

a) Irrigation scheduling maximizes ET and minimizes drainage while achieving potential yield with the minimum required amount of irrigation water.

b) Irrigation scheduling increases irrigation efficiency by never exceeding the water holding capacity of the soil during an irrigation.

c) Irrigation scheduling will not automatically increase net profitability. For producers already applying the correct amount of water at appropriate intervals using some other method (calendar, experience, etc.), scheduling offers no economic incentive. Alternatively, producers who are unable to correctly monitor crop water use and are over or under irrigating can very likley increase their net profit by scheduling their irrigations.

d) Irrigation schedules can be calculated in a variety of ways, however, to insure proper irrigation levels it is imperative that field checks are made on a regular basis.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Irrigation scheduling is a viable irrigation management technique which can conserve water, minimize drainage and maximize crop yield. It is a scientific approach to irrigation which elimates much of the guesswork of when and how much to irrigate. The economic superiority of irrigation scheduling, however, is not as easily determined. Scheduling offers little or no economic incentive to irrigators who have access to large amounts of inexpensive water, or to those who irrigate by flooding or gravity flow. Since the costs of irrigation are minimal there is little motivation to conserve resources. Such is the case in much of the Cache Valley, Utah area. For these reasons it is doubtful that the technique of irrigation scheduling will be adopted by irrigators in that area.

Irrigation scheduling does offer economic incentive to irrigators who have high input costs (labor, power or water) or who are "over or under" irrigating without realizing it. Scheduling can help a farmer "calibrate" the water demanded by certain crops on specific fields, thereby elimating excessive drainage caused by over irrigation or crop stress brought on by under irrigation. In fact, once a field is calibrated it may not be necessary to schedule irrigations each year. After several years of scheduling, an established pattern of irrigations (both amount per irrigation and frequency between) may become evident. If so, the irrigator may choose to simply follow the pattern, adjusting it to changes in the climate when necessary. By so doing, the costs of irrigation scheduling would be avoided while enjoying the benefits.

Recommendations for Further Study

The simulation modeling would be improved with crop coefficients (Kc) obtained from the U.S.U. Experiment Station (Kc data from Huntington, Utah were used in this study). Actual field experiments with irrigation scheduling on alfalfa hay in conjunction with computer modeling would prove invaluable in helping to calibrate the model.

Additional empirical study by soil and plant scientists on the yield impact of over irrigation would provide important data needed by economists and irrigation engineers when examining crop-water relationships.

Further work should be done to assess the economic impact of the recent electricity time-of-use rates on irrigators. Whether an irrigator decides to pump during peak load, shoulder or off-peak may be a factor of the type of irrigation schedule chosen. Simulation modeling could provide an excellent basis for determining the economically optimal irrigation schedule under different time of use pumping options.

Modeling or emperically studying the economic impact of irrigation scheduling on crops such as corn, wheat, barley, potatoes and others, is an additional area worthy of research efforts.

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APPENDIXES

Appendix A
Example of the Eo, Ep, Kc, and Tp Data Transformation

YEAR= 1981

FIRST CROP

DATE	CUM DAYS	PAN EVAP OR EO	5 DY EO AVE.	KC COEF	POT. EP	5 DY EP AVE.	POT. TP	RAIN
AP 15	1	.17		.98	.167		.003	0
16	2	.2		.98	.196		.004	0
*17	3	.08	.16	.98	.078	.157	.002	0
18	4	.25		.98	.245		.005	0
19	5	.1		.98	.098		.002	.4
20	6	.15		.98	.147		.003	.11
21	7	.02		.7	.014		.006	.27
*22	8	.1	.184	.7	.07	.137	.03	0
23	9	.41		.7	.287		.123	0
24	10	.24		.7	.168		.072	0
25	11	.21		.7	.147		.063	0
26	12	.22		.7	.154		.066	0
*27	13	.11	.172	.5	.055	.103	.055	.02
28	14	.11		.5	.055		.055	0
29	15	.21		.5	.105		.105	0
30	16	.18		.5	.09		.09	0
MAY 1	17	.03		.5	.015		.015	0
*2	18	.08	.138	.05	.004	.026	.076	.21
3	19	.13		.05	.007		.124	0
4	20	.27		.05	.014		.257	0
5	21	.19		.05	.01		.181	0
6	22	.17		.05	.009		.162	.36
*7	23	.09	.15	.05	.005	.008	.086	.01
8	24	.1		.05	.005		.095	.02
9	25	.2		.05	.01		.19	0
10	26	.23		.05	.012		.219	0
11	27	.11		.05	.006		.105	.5
*12	28	.19	.17	.05	.01	.009	.181	0
13	29	.18		.05	.009		.171	0
14	30	.14		.05	.007		.133	0
15	31	.17		.05	.009		.162	.66
16	32	.05		.05	.003		.048	.01
*17	33	.06	.13	.05	.003	.007	.057	.21
18	34	.11		.05	.006		.105	0
19	35	.26		.05	.013		.247	0
20	36	.04		.05	.002		.038	.24
21	37	.09		.05	.005		.086	.88

Appendix B
Yearly Production Data From the Model Simulation

No Irrigation

YEAR	ET	TRANS	* DRAIN	YIELD
1953	14.7	11.2	.2	.543
1954	12.5	8.2	0	.349
1955	15.2	10	0	.482
1956	12.9	9.1	0	.433
1971	15.4	11.1	1	.603
1972	13	8.4	.2	.404
1973	17.2	11.6	.2	.539
1974	11.7	8.8	0	.406
1975	15.2	10.3	1.1	.533
1976	16	10.6	1	.486
1977	17.2	13.3	0	.691
1978	13	9.3	.4	.485
1979	13.8	9.5	.2	.471
1980	18.7	13.1	.6	.684
1981	17.1	12.4	0	.657
1982	15.4	9.5	0	.508
AVE >>	14.94	10.40	0.31	0.52

* DUE TO RAINFALL

General Data

YEAR	SEASON RAIN	PAN EVAP (CVAP)
1953	5.6	35.6
1954	3.2	38.1
1955	6	34.3
1956	3.6	34.9
1971	7.9	31.3
1972	4.5	34.5
1973	10.3	34.1
1974	2.4	36.9
1975	7	31.3
1976	8.4	34.3
1977	8.8	34.2
1978	4.1	32.4
1979	4.7	32.7
1980	10.3	34.4
1981	7.8	32.3
1982	6.5	31.8
AVE >>	6.32	33.94

Appendix B (cont.)
Model-Calculated Irrigation Schedules

YEAR	# OF IRRIG	GROSS IRRIG WATER	IRRIG DRAIN	NET IRRIG WATER	AVE WATER PER IRRIG	TOTAL HOURS SPENT PUMPING	AVE PUMPING HOURS PER IRRIG	ET	TRANS	YIELD	WATER APPL EFFIC
1953	8	16.8	0	16.8	2.10	56	7.00	28.1	20.3	.988	1.00
1954	11	22.6	0	22.6	2.05	75	6.85	33	22.9	.98	1.00
1955	9	18	0	18	2.00	60	6.67	30.8	20.4	.982	1.00
1956	8	19.8	0	19.8	2.48	66	8.25	30.1	20.6	.98	1.00
1971	9	15.5	0	15.5	1.72	52	5.74	27	18.2	.993	1.00
1972	10	19.3	0	19.3	1.93	64	6.43	29	20.5	.986	1.00
1973	8	16.7	0	16.7	2.09	56	6.96	30.3	21.4	.991	1.00
1974	10	21	0	21	2.10	70	7.00	30.4	21.3	.982	1.00
1975	8	15.7	0	15.7	1.96	52	6.54	28.3	19	.983	1.00
1976	8	18.1	0	18.1	2.26	60	7.54	31.1	21.5	.987	1.00
1977	8	12	0	12	1.50	40	5.00	27.3	19	.986	1.00
1978	7	18.1	0	18.1	2.59	60	8.62	28.1	18.8	.978	1.00
1979	9	16.9	0	16.9	1.88	56	6.26	27.4	20.1	.995	1.00
1980	5	10.8	0	10.8	2.16	36	7.20	27.2	19	.99	1.00
1981	5	11.5	0	11.5	2.30	38	7.67	26.3	18.5	.981	1.00
1982	8	15.6	0	15.6	1.95	52	6.50	28.4	18.5	.989	1.00
AVE >>	8.19	16.78	0.00	16.78	2.07	55.92	6.89	28.93	20.00	0.99	1.00

Appendix B (cont.)
Five Irrigations

	INCHES OF WATER/IRR 1				INCHES OF WATER/IRR > 2				INCHES OF WATER/IRR > 3			
YEAR	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD
1953	12.9	19.3	0	.626	17.5	24.1	0	.851	19.7	26.2	2	.956
1954	10.3	17.1	0	.441	15	22	0	.639	19.7	26.8	0	.842
1955	12.3	19.9	0	.592	16.7	24.6	0	.805	20.3	28.2	0	.978
1956	10.9	17.4	0	.521	15.4	22.3	0	.734	19.7	26.5	0	.936
1971	13.7	20.4	0	.745	17.3	24.4	0	.941	18.4	25.5	1.2	.999
1972	11.3	17.7	0	.547	16	22.4	0	.77	19.8	26.2	0	.953
1973	15.4	22.2	0	.715	19.7	26.5	0	.916	21.5	28.3	0	.999
1974	10.2	16.3	0	.47	14.5	21.2	0	.672	19.1	25.8	0	.883
1975	13.3	19.6	0	.687	17.6	23.9	0	.913	19.3	25.6	.6	.999
1976	14.6	21	0	.67	19.1	25.6	0	.878	21.3	27.8	0	.98
1977	15.2	21.5	0	.788	18.1	24.7	0	.942	19.1	25.7	.7	.993
1978	11.2	17.5	0	.581	15.7	22.2	0	.813	18.9	25.4	.3	.979
1979	13	18.4	0	.645	17.3	23.1	0	.858	20.1	25.9	0	.995
1980	15	22.3	1	.78	17.9	25.6	2.1	.932	19.1	26.8	4.1	.995
1981	14.1	21	.6	.75	17.1	24.2	1.8	.91	18.6	25.7	3.8	.99
1982	12.3	19.9	0	.656	16.8	24.4	0	.898	18.7	26.4	0	1
AVE >	12.86	19.47	0.10	0.64	16.98	23.83	0.24	0.84	19.58	26.43	0.79	0.97

	INCHES OF WATER/IRR 4				INCHES OF WATER/IRR > 5				INCHES OF WATER/IRR > 6			
YEAR	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD
1953	20.6	27.1	4	.999	20.6	27.1	8.2	1	20.6	27.1	13.2	1
1954	22.8	29.9	0	.974	23.3	30.4	2.2	.995	23.3	30.4	7.2	.995
1955	20.7	28.7	1.2	1	20.7	28.7	6	1	20.7	28.7	11	1
1956	21	27.9	0	1	21	27.9	4.5	1	21	27.9	9.5	1
1971	18.4	25.5	3.2	1	18.4	25.5	8.2	1	18.4	25.5	13.2	1
1972	20.7	27.2	0	.998	20.7	27.2	4.3	1	20.7	27.2	9.3	1
1973	21.5	28.3	2.3	1	21.5	28.3	7.3	1	21.5	28.3	12.3	1
1974	21.5	28.2	0	.993	21.6	28.3	2.9	1	21.6	28.3	7.9	1
1975	19.3	25.6	4.1	1	19.3	25.6	9.1	1	19.3	25.6	14.1	1
1976	21.7	28.2	2.2	1	21.7	28.2	7.2	1	21.7	28.2	12.2	1
1977	19.2	25.8	5.6	1	19.2	25.8	10.6	1	19.2	25.8	15.6	1
1978	19.2	25.8	1.6	.999	19.3	25.8	6.6	1	19.3	25.8	11.6	1
1979	20.2	26	2.5	1	20.2	26	7.5	1	20.2	26	12.5	1
1980	19.2	26.9	6.7	1	19.2	26.9	11.7	1	19.2	26.9	16.7	1
1981	18.8	25.9	6.2	1	18.8	25.9	11.2	1	18.8	25.9	16.2	1
1982	18.7	26.4	3.2	1	18.7	26.4	8.2	1	18.7	26.4	13.2	1
AVE >	20.22	27.09	2.68	1.00	20.26	27.13	7.23	1.00	20.26	27.13	12.23	1.00

Appendix B (cont.)
Five Irrigations

	INCHES OF WATER/IRR > 7				INCHES OF WATER/IRR > 8			
YEAR	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD
1953	20.6	27.1	18.2	1	20.6	27.1	23.2	1
1954	23.3	30.4	12.2	.995	23.3	30.4	17.2	.995
1955	20.7	28.7	16	1	20.7	28.7	21	1
1956	21	27.9	14.5	1	21	27.9	19.5	1
1971	18.4	25.5	18.2	1	18.4	25.5	23.2	1
1972	20.7	27.2	14.3	1	20.7	27.2	19.3	1
1973	21.5	28.3	17.3	1	21.5	28.3	22.3	1
1974	21.6	28.3	12.9	1	21.6	28.3	17.9	1
1975	19.3	25.6	19.1	1	19.3	25.6	24.1	1
1976	21.7	28.2	17.2	1	21.7	28.2	22.2	1
1977	19.2	25.8	20.6	1	19.2	25.8	25.6	1
1978	19.3	25.8	16.6	1	19.3	25.8	21.6	1
1979	20.2	26	17.5	1	20.2	26	22.5	1
1980	19.2	26.9	21.7	1	19.2	26.9	26.7	1
1981	18.8	25.9	21.2	1	18.8	25.9	26.2	1
1982	18.7	26.4	18.2	1	18.7	26.4	23.2	1
AVE >	20.26	27.13	17.23	1.00	20.26	27.13	22.23	1.00

<<<< 16 YEAR AVERAGES >>>

INCH/ IRR	TRANS	ET	IRRIG DRAIN	YIELD	WATER APPL EFFIC
1	12.86	19.47	0.10	0.64	.98
2	16.98	23.83	0.24	0.84	.98
3	19.58	26.43	0.79	0.97	.95
4	20.22	27.09	2.67	1.00	.87
5	20.26	27.13	7.23	1.00	.71
6	20.26	27.13	12.23	1.00	.59
7	20.26	27.13	17.23	1.00	.51
8	20.26	27.13	22.23	1.00	.44

Appendix B (cont)
Eight Irrigations

INCHES OF
WATER/IRR 1

YEAR	TRANS	ET	DRAIN	YIELD
1953	15.2	22.1	0	.737
1954	12.8	20	0	.546
1955	14.9	22.7	0	.72
1956	13.5	20.3	0	.642
1971	15.4	22.5	0	.837
1972	13.8	20.5	0	.664
1973	17.1	24.2	0	.793
1974	12.5	19.2	0	.578
1975	15.8	22.3	0	.816
1976	17.2	23.9	0	.791
1977	16.9	23.5	0	.878
1978	13.8	20.3	0	.717
1979	15.3	21.2	0	.757
1980	16.4	24.1	2	.854
1981	15.8	23.1	1.2	.838
1982	14.9	22.6	0	.795
AVE >	15.08	22.03	0.20	0.75

INCHES OF
WATER/IRR > 2

YEAR	TRANS	ET	DRAIN	YIELD
1953	19.9	26.9	2	.967
1954	20	27.3	0	.853
1955	20.5	28.6	0	.991
1956	19.9	27.1	0	.947
1971	18.3	25.7	1.2	.999
1972	19.7	26.5	0	.952
1973	21.5	28.6	0	.997
1974	19.4	26.4	0	.894
1975	19.3	25.8	.9	1
1976	21.6	28.3	0	.993
1977	19.2	26.1	.7	.999
1978	19.1	25.8	.3	.99
1979	20.2	26.3	0	.999
1980	19.2	26.9	4.1	.999
1981	18.7	26.1	3.8	.995
1982	18.7	26.5	0	1
AVE >	19.70	26.81	0.81	0.97

INCHES OF
WATER/IRR > 3

YEAR	TRANS	ET	DRAIN	YIELD
1953	20.6	27.6	5.2	1
1954	23.4	30.7	0	.998
1955	20.7	28.8	3.3	1
1956	21	28.2	1.6	1
1971	18.4	25.7	6	1
1972	20.7	27.5	1.5	1
1973	21.5	28.6	5.7	1
1974	21.6	28.7	.1	1
1975	19.3	25.8	6	1
1976	21.7	28.5	4.6	1
1977	19.2	26.1	8.5	1
1978	19.3	26	3.6	1
1979	20.2	26.3	4.4	1
1980	19.2	27	8.8	1
1981	18.8	26.2	8	1
1982	18.7	26.5	5.5	1
AVE >	20.27	27.39	4.55	1.00

INCHES OF
WATER/IRR 4

YEAR	TRANS	ET	DRAIN	YIELD
1953	20.6	27.6	12.2	1
1954	23.4	30.8	6.5	.999
1955	20.7	28.8	11.3	1
1956	21	28.2	9.3	1
1971	18.4	25.7	13.9	1
1972	20.7	27.5	9.5	1
1973	21.5	28.6	13.7	1
1974	21.6	28.7	7.8	1
1975	19.3	25.8	14	1
1976	21.7	28.5	12.6	1
1977	19.2	26.1	16.5	1
1978	19.3	26	11.6	1
1979	20.2	26.3	12.4	1
1980	19.2	27	16.8	1
1981	18.8	26.2	15.6	1
1982	18.7	26.5	13.5	1
AVE >	20.27	27.39	12.33	1.00

INCHES OF
WATER/IRR > 5

YEAR	TRANS	ET	DRAIN	YIELD
1953	20.6	27.6	20	1
1954	23.4	30.8	14.5	1
1955	20.7	28.8	19.3	1
1956	21	28.2	17.3	1
1971	18.4	25.7	21.9	1
1972	20.7	27.5	17.5	1
1973	21.5	28.6	21.7	1
1974	21.6	28.7	15.8	1
1975	19.3	25.8	22	1
1976	21.7	28.5	20.6	1
1977	19.2	26.1	24.5	1
1978	19.3	26	19.6	1
1979	20.2	26.3	20.4	1
1980	19.2	27	24.8	1
1981	18.8	26.2	23.6	1
1982	18.7	26.5	21.5	1
AVE >	20.27	27.39	20.31	1.00

INCHES OF
WATER/IRR > 6

YEAR	TRANS	ET	DRAIN	YIELD
1953	20.6	27.6	28	1
1954	23.4	30.8	22.5	1
1955	20.7	28.8	27.3	1
1956	21	28.2	25.3	1
1971	18.4	25.7	29.9	1
1972	20.7	27.5	25.5	1
1973	21.5	28.6	29.7	1
1974	21.6	28.7	23.8	1
1975	19.3	25.8	30	1
1976	21.7	28.5	28.6	1
1977	19.2	26.1	32.5	1
1978	19.3	26	27.6	1
1979	20.2	26.3	28.4	1
1980	19.2	27	32.8	1
1981	18.8	26.2	31.6	1
1982	18.7	26.5	29.5	1
AVE >	20.27	27.39	28.31	1.00

Appendix B (cont.)
Eight Irrigations

	INCHES OF WATER/IRR > 7				INCHES OF WATER/IRR > 8			
YEAR	TRANS	ET	DRAIN	YIELD	TRANS	ET	DRAIN	YIELD
1953	20.6	27.6	36	1	20.6	27.6	44	1
1954	23.4	30.8	30.5	1	23.4	30.8	38.5	1
1955	20.7	28.8	35.3	1	20.7	28.8	43.3	1
1956	21	28.2	33.3	1	21	28.2	41.3	1
1971	18.4	25.7	37.9	1	18.4	25.7	45.9	1
1972	20.7	27.5	33.5	1	20.7	27.5	41.5	1
1973	21.5	28.6	37.7	1	21.5	28.6	45.7	1
1974	21.6	28.7	31.8	1	21.6	28.7	39.8	1
1975	19.3	25.8	38	1	19.3	25.8	46	1
1976	21.7	28.5	36.6	1	21.7	28.5	44.6	1
1977	19.2	26.1	40.5	1	19.2	26.1	48.5	1
1978	19.3	26	35.6	1	19.3	26	43.6	1
1979	20.2	26.3	36.4	1	20.2	26.3	44.4	1
1980	19.2	27	40.8	1	19.2	27	48.8	1
1981	18.8	26.2	39.6	1	18.8	26.2	47.6	1
1982	18.7	26.5	37.5	1	18.7	26.5	45.5	1
AVE >	20.27	27.39	36.31	1.00	20.27	27.39	44.31	1.00

<<<< 16 YEAR AVERAGES >>>

INCH/ IRR	TRANS	ET	IRRIG DRAIN	YIELD	WATER APPL EFFIC
1	15.08	22.03	0.20	0.75	.98
2	19.70	26.81	0.81	0.97	.95
3	20.27	27.39	4.55	1.00	.81
4	20.27	27.39	12.33	1.00	.61
5	20.27	27.39	20.31	1.00	.49
6	20.27	27.39	28.31	1.00	.41
7	20.27	27.39	36.31	1.00	.35
8	20.27	27.39	44.31	1.00	.31

Appendix C
Irrigation Efficiency Equations
(Israelsen and Hansen)

Water Conveyance Efficiency:

$$Ec = 100\,(Wf / Wr)$$

where: Ec = Water conveyance efficiency
Wf = Water delivered to farm
Wr = Water diverted from source (canal, river, pond, etc.)

Water Use Efficiency:

$$Eu = 100\,(Wu / Wd)$$

where: Eu = Water use efficiency
Wu = Water beneficially used
Wd = Water delivered to farm

Water Storage Efficiency:

$$Es = 100\,(Ws / Wn)$$

where: Es = Water storage efficiency
Wu = Water stored in root zone during the irrigation
Wn = Water needed in the root zone prior to the irrigation

Water Distribution Efficiency:

$$Ed = 100\,(1 - (y/d))$$

where: Ed = Water distribution efficiency
y = average numerical deviation in depth of water stored from average depth stored during the irrigation
d = average depth of water stored during the irrigation

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