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Irrigation Scheduling Using Crop Growth Simulation, Risk Analysis, and Weather Forecasts

D. H. Rogers, R. L. Elliott
ASSOC. MEMBER ASAE   MEMBER ASAE

ABSTRACT

Irrigation schedules for grain sorghum in the Panhandle of Oklahoma were determined using a cost/loss risk analysis (C/L) procedure, a crop growth simulation model, and rainfall forecasts. Ten rainfall probability sequences were investigated using probabilities based on either climatological records, professional forecasts, or a combination thereof. The costs associated with applying irrigation on a daily basis were compared to the loss of yield (crop value) due to deficit soil water.

Whenever the C/L ratio reached a critical level, as determined by the probability of rainfall, irrigation was initiated in the simulation. Economic return and total irrigation water application from a the various scheduling methods were compared to schedules based on soil water status and stage of growth criteria that had previously been identified as improved irrigation management practices.

The C/L methodology developed different schedules for the three C/L ratios used and resulted in decreasing water application as irrigation cost increased or crop value decreased. No rainfall probability estimate was clearly superior in determining schedules, although those associated with a critical rainfall amount tended to have higher return. The C/L schedules tended to have slightly lower return than did stage of growth schedules. However, C/L schedules applied less total irrigation water, particularly for high irrigation cost/low crop value ratios, indicating the procedure may have merit in determining irrigation schedules where water resources are limited.

INTRODUCTION

Water is a key resource for agriculture that often limits crop production. Profitable irrigated crop production requires intensive management of limited and/or expensive water supplies relative to water-related production losses. Optimization of irrigation management strategies and systems has been actively pursued by many individuals.

One aspect of improved irrigation management strategy centers on the use of irrigation scheduling. The decision as to whether to begin irrigation or not is at the discretion of the manager who must base the decision on an analysis of current information and a subjective consideration of future events. In recent years, crop growth models have been developed that can accurately represent growth processes. They can, therefore, be used to analyze the effects of a current management decision against various probable future events to aid in determination of the best course of action.

Objective

The major objective of this study was to use a crop growth model to compare various irrigation management strategies on a real-time basis. Simulation results from a decision-making process which utilized a risk analysis procedure and weather forecasts were compared to results from simulation using soil water depletion and stage of growth irrigation criteria.

REVIEW OF LITERATURE

Boggess et al. (1983) reviewed approximately 50 articles to determine the specific irrigation management objectives and how the issue of variability (risk or uncertainty) was addressed. Their review indicated mainly single dimensional criteria in the decision-making process. They divided the approaches into three categories of management objectives: maximization of unconstrained yield, maximization of unconstrained profit, and alternative maximization or minimization objectives subject to various constraints. Hill et al. (1983) and Hill and Keller (1983) were studies which used yield optimization as an objective. Those using profit optimization include Martin et al. (1983), Martin and Heermann (1984), Swaney et al. (1983a), and Lansford et al. (1983). A number of studies fall into the third category and include Khanjani and Busch (1982), Kundu et al. (1982), Martin and van Brocklin (1985), Pleban et al. (1984), Ramirez and Bras (1985), Seginer (1983), and Smith et al. (1985).

Risk and uncertainty play a role in agricultural production. Irrigated agriculture has traditionally been considered as a method of bringing stability to crop production through reduced yield variability and reduced income variability. Boggess et al. (1983) identified five risk (variability) sources; all but institutional uncertainty were quantified in their analysis. A process simulation model was used to analyze the impact of alternative irrigation strategies on risks and net returns above irrigation costs, and results were presented for objectives of maximum net return, maximum yield, and maximum return per unit of irrigation water.

English and Orlob (1978) developed a general

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The authors are: D. H. ROGERS, Extension Engineer, Kansas State University, Manhattan, and R. L. ELLIOTT, Associate Professor, Agricultural Engineering, Oklahoma State University, Stillwater.

analytical model for dealing with the complex uncertainties in the relationship between irrigation water use and net farm income. They determined that optimal irrigation strategies which disregard uncertainty and utility could be substantially different than strategies accounting for uncertainty and utility. Utility, in this instance, was the decision-maker's attitude toward risk.

Others also have included variability due to production factors as part of their decision-making process, including Boggess and Amerling (1983), Cull et al. (1981a), and English et al. (1985). Simulation methodology effects were noticed by Dugas and Ainsworth (1985) and Udeh and Busch (1982).

English (1981) indicated that models that do not account for uncertainty are inadequate and concluded that a real need exists for crop models that not only preduct the most profitable yield, but also quantify the uncertainty of the yield prediction. Loftis (1981) had noted that the dynamic programming procedure provides a potentially powerful tool for scheduling irrigation, but has limitations due to uncertainties imposed by the crop growth models.

Although certain limitations have been expressed, crop growth simulation has been successfully combined with various decision-making criteria in determining improved irrigation schedules. Successful use of such models is dependent upon clear understanding of the input requirements and model limitations. The use of crop growth models, in combination with other models and decision-making criteria, has potentially added another dimension to the crop manager's decision-making capability. Ahmed et al. (1976), Cull et al. (1981b), Amir et al. (1976), and Amir et al. (1980) suggest that crop growth models can be a useful water resource management tool.

Calculated Risk and Weather Forecasts

Calculated risk is a decision-making process which involves a comparison of an expected loss to the cost of preventing the occurrence of the expected loss. In terms of irrigation scheduling programs, the expected loss could be yield reductions due to insufficient soil water; the cost of prevention could be the cost of applying irrigation water and preventing the insufficient soil water condition. Gringorten (1950) and Thompson (1950) applied the principle of calculated risk to repetitive operations where weather was the uncertain factor.

Thompson and Brier (1955) outlined the development of the calculated risk concept for weather sensitive operations. Murphy (1976) generalized the concept to fit a wider range of problems. The concept is as follows:

If:	Then:
$P > C/L$	Protect
$P = C/L$	Either course
$P < C/L$	Do not protect

Where:

P = the probability of the loss occurring
C = the cost of protective measures
L = the loss incurred should no protective action by taken

Murphy (1976) noted that this procedure would minimize the decision-maker's expected expense for the particular operation. In the case of irrigation scheduling, C is the cost of irrigation and L is the loss in the value of crop yield due to insufficient soil water.

Thompson (1963) illustrated the application of the calculated risk concept and demonstrated a method of analyzing weather forecast predictions allowing relatively inaccurate forecasts to be used beneficially.

An important part of the C/L model is the probability of occurrence of the particular adverse weather condition of concern to the decision-making process. The economics of extended-term forecasting were examined by Anderson (1973). Murphy (1977) also investigated the value of weather forecasts including the following types: 1) climatological (i.e., forecasts based upon climatological probabilities, derived from historical records); 2) categorical or deterministic (i.e., forecasts derived from comparing forecast probabilities with some critical probability value, for example, probability of rain given the previous day had rain); and 3) probabilistic forecasts (i.e., professional forecasts). The effect of perfect forecasts in the decision-making process was also included. Important implications of the study were that the value of even moderately unreliable probabilistic forecasts exceeds the value of climatological and categorical forecasts and that benefits expected from using probabilistic forecasts in a decision-making process do not depend on scientific advances in weather forecasting.

Allen and Lambert (1971a) discussed the principle of calculated risk. The general decision-making model combined weather forecast data, crop production information, and irrigation costs into a probability framework. Allen and Lambert (1971b) discussed the application of the calculated risk principles for a specific situation from which they concluded the resulting irrigation schedule was superior to a scheduling program based on a specific level of soil water availability.

Fouss (1985) combined 12 hour weather forecasts into a single daily rainfall probability that was used as an input to a water management simulation model. The rainfall probability factor was used as a categorical type input; that is, if the probability of rainfall exceeded a predetermined critical value, a particular course of action was taken.

A dynamic decision-making model was used by Brown et al. (1986) to investigate the economic benefits of forecasts in the fallow/plant situation for wheat. Current seasonal precipitation forecasts, issued by the National Weather Service, had minimal economic value, although modest improvements in the forecasts could lead to large increases in their value. The value of forecasts was sensitive to crop price and precipitation climatology.

Hashemi and Decker (1969) used climatological data and precipitation probability forecasts to schedule irrigations. In this instance, the effects on crop yield were not evaluated as the analysis assumed maintenance of soil water above a critical value for crop yield damage. Benefits were gained by incorporating weather information into the decision-making process because of the resulting reductions in both frequency and amount of irrigation water applied.

Mishoe et al. (1982), and Swaney et al. (1983a, b), used SOYGRO, a soybean growth model, to make real-time irrigation decisions and evaluate the sensitivity of the analysis to various methods of predicting future weather conditions. The sequential use of the real-time decision model was superior to the long-term strategy. The evaluation of model sensitivity indicated that averaged weather conditions were inadequate for model use. Historically based precipitation probabilities were superior to the averaged weather conditions, but no additional improvements in profits were noted when daily forecasts of precipitation probabilities were used. They concluded that the lack of improvement with forecast probabilities was due to the nature of the tropical thundershowers of the region.

PROCEDURES

Study Area

The general geographical area studied was the Panhandle of Oklahoma. The irrigation water supply for the region is from the Ogallala aquifer, and grain sorghum is the major irrigated crop. The summer growing season conditions are characterized by sparse precipitation, high temperatures, and frequent strong winds. The majority of the average annual rainfall, which is about 44 cm, falls during spring and summer months. The soils of the region are generally deep loams and clay loams. Weather data used in this study were collected at Goodwell, Oklahoma, near the center of the study area.

Crop Model

SORGF, the crop model selected for this project, was developed by Arkin, Vanderlip, and Ritchie (1976). SORGF is comprised of a series of submodels that represent particular physical characteristics and physiological growth processes of a grain sorghum plant. The model is sensitive to many production factors including row spacing, plant population, the type of hybrid, ambient temperatures, daily solar radiation, and available soil water. Maas and Arkin (1978) prepared the user's guide to SORGF which provides detailed descriptions of the submodels. Maas and Arkin (1980) performed a sensitivity analysis on SORGF, and indicated that the model showed a response to changes consistent with current understanding of plant/environment relationships. Additional evaluation and verification of model performance was conducted by Rogers (1988). Arkin et al. (1978) used a combination of the crop model and stochastic weather data to provide a realistic method of yield forecasting. Other studies, including Arkin and Dugas (1981), Harris (1981), Harris and Mapp (1986), Hornbaker (1985), Ham (1986), and Zavaleta et al. (1980), have used SORGF or versions thereof.

Improved Contemporary Irrigation Practices

The calculated risk analysis was evaluated by comparing it to irrigation scheduling criteria that had been developed in a previous study. Harris and Mapp (1986) and Harris (1981) defined contemporary irrigation practices for the Panhandle of Oklahoma as applying 61 cm (24 in.) of irrigation water per year regardless of climatic conditions or soil water availability. They examined a variety of irrigation schedules using stochastic efficiency and optimal control procedures.

Harris and Mapp (1986) identified irrigation scenarios which resulted in increased net returns and water savings over contemporary irrigation practices. Efficient irrigation scenarios selected from Harris and Mapp for comparison to schedules generated using risk analysis are: 1) irrigations initiated at or below an extractable soil water ratio of 45%, and 2) three scenarios with the 45% limit and irrigation withheld during either growth stage 1, stage 3, or a combination of growth stages 1 and 3. Extractable soil water is water available to the plant between field capacity and permanent wilting point. These represent the best options from the scenario combinations described by Harris and Mapp.

Cost/Loss Risk Analysis

The C/L risk analysis method requires that irrigation be initiated only when the probability of loss occurrence is greater than the C/L ratio. The probability of loss occurrence is one minus the daily rainfall probability. Calculation of the C/L ratio requires information about the daily cost of irrigation and the daily loss of crop value due to deficient soil water.

Daily irrigation costs considered only fuel operating expenses. Typical pumping depths, discharge capacities, operating pressures, and system efficiencies were determined and pumping costs were estimated using Nebraska performance criteria (Schleusener and Sulek, 1959) and a representative natural gas price of \$0.12/m^3 (\$3.40/MCF). The operating costs were calculated by determining the total expense for fuel for a given net application. This total expense was then divided by the number of hectares in the field and then by the number of days required to complete irrigation over the entire field. This made the irrigation cost independent of application amount, since altering application depth changes both the time to complete an irrigation and the number of hectares irrigated per day. The resulting cost of irrigation was selected to be \$1.75/ha-day and was considered representative of both surface and center pivot systems of the region. Two application depths (2.5 cm and 7.5 cm) were selected for use in the analysis to represent typical application depths of center pivot and surface irrigation.

The loss of crop value due to deficit soil water was calculated by making crop yield projections. SORGF was modified for this study by incorporating submodels into the program to make yield projections based on historical weather data (Fig. 1). The addition to SORGF begins at the end of a day's growth simulation. After leaving the maturity decision block with a "No" answer, the program enters a decision block to determine if a yield projection should be made. The decision block's main purpose was to check if an irrigation application was complete, since another irrigation could not be applied until the first had been completed.

The yield projection procedures were essentially those in the current SORGF version with the exception that daily soil water levels were maintained at 75% of UL (Upper Limit of soil water holding capacity). Seventy-five percent of UL was selected to represent the average condition for a well-watered irrigated crop from the yield projection date to the end of the season. The yield projections were made using the historical average for

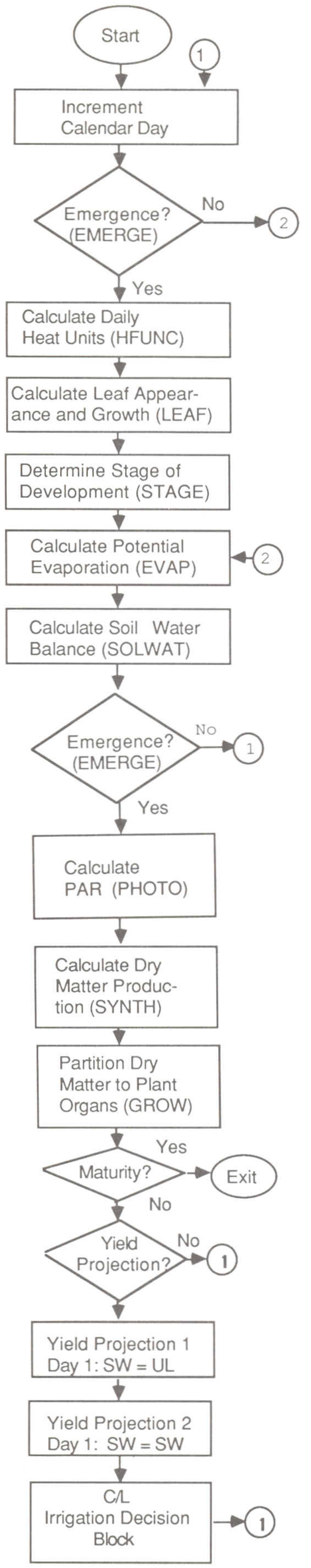

Fig. 1—Simplified flow diagram of SORGF with risk analysis for irrigation decision-making.

maximum and minimum temperatures for Goodwell, Oklahoma. Long-term solar radiation values were not available at Goodwell, requiring solar radiation data from Dodge City, Kansas to be used as an estimate for Goodwell conditions.

The difference in yield projection 1 and yield projection 2 lies in the first day's soil water. Projection 2 was the yield based on the first day of the projection having a soil water value equal to the current soil water level and then all remaining days with the soil water set to 75% of UL. Projection 1 was the yield based on all days' soil water being set at 75% of UL. The difference in these values was the estimated yield loss for a one-day delay in applying irrigation water. The loss in crop value was the daily yield loss times the crop price. This loss was carried forward into the next module where the decision on whether or not to apply irrigation water was made.

The irrigation time interval also affects the yield of plants based on their position within the field, the extremes of which are the first and last plant to receive water. To account for the yield difference between the first and last plants in the field, yields for both were modeled. First plant irrigation dates were established by the irrigation scheduling criteria, and the date of the last plant irrigation was then determined based on the irrigation system capacity. These dates were entered into the model to determine last plant yield. The two yields were averaged to make an estimate of the average field yield.

SORGF was also modified to allow the final irrigation amount to be reduced in proportion to the days remaining until physiological maturity of the crop. The date of physiological maturity was projected each time a yield projection was made. This prevents SORGF from initiating an irrigation requiring many days to apply when only a few days remain until physiological maturity. The resulting yields are similar to fully irrigated yields without the entire expense of the full irrigation being charged.

The irrigation scheduling decision was based on a ratio of the cost and loss values in the C/L risk analysis model. The loss was the representative price ($0.66/kg or $3.00/cwt) times the yield loss projected by the SORGF simulation model. This can be represented as

$$\frac{C}{L} = \frac{\$1.75/\text{ha-day}}{\$0.066/\text{kg}*\text{YL}} = \frac{26.52}{\text{YL}}$$

where YL is the projected yield loss in kg/ha-day.

Two other C/L ratios were also used in determining irrigation schedules. One was based on a low irrigation cost to crop price ratio (C/L = 13.26/YL), and the other on a high irrigation cost to crop price ratio (C/L = 53.03/YL). These three ratios do not represent all possible combinations of crop prices and irrigation costs, although they do represent a fairly extreme range of combinations. Irrigation cost shifts can reflect changes in either fuel price, pumping plant efficiency, additional irrigation expenses such as labor and maintenance, or some combination. Each of these three C/L ratios was incorporated into the irrigation decision submodel of SORGF and used to produce irrigation schedules for each of the various methods of defining the rainfall

TABLE 1. Methods of irrigation scheduling

Method Number	Abbreviation	Method of Scheduling Irrigation
1	GSO	No growth stage restrictions (from Harris, 1981)
2	GS1	Irrigation withheld growth stage 1 (from Harris, 1981)
3	GS3	Irrigation withheld growth stage 3 (from Harris, 1981)
4	GS13	Irrigation withheld growth stage 1 & 3 (from Harris, 1981)
5	DAILY	Daily climatological probability
6	DAILYCV	Daily climatological probability for rainfall $>$ .635 cm
7	COND	Conditional daily climatological probability (previous day wet or dry)
8	CONDCV	Conditional daily climatological probability for rainfall $>$ .635 cm (previous day wet or dry)
9	FCST	Probabilistic forecast
10	COMFCST	Comparative probabilistic forecast
11	CONDFCST	Conditional comparative probabilistic forecast
12	COMFCV	Comparative probabilistic forecast for rainfall $>$ .635 cm
13	CONDFCV	Conditional comparative probabilistic forecast for rainfall $>$ .635 cm
14	PERFECT	Perfect forecast

probability.

Ten different estimates of rainfall probabilities were developed. Each rainfall probability estimate was used in the C/L method of irrigation scheduling. These schedules and the schedules from Harris (1981) are shown in Table 1. These estimates of rainfall probability fall into two general classes; 1) climatological, and 2) probabilistic. The climatological forecasts are those based upon historical probabilities. The daily rainfall amounts recorded since 1948 at Goodwell, Oklahoma were used to prepare the rainfall probabilities shown as methods 5 through 8 in Table 1. The probabilistic forecasts utilized are those prepared by the National Weather Service (NWS) for 1984 through 1987. NWS forecasts are issued in 10% increments (0%, 10%, 20%, etc.). Modifications of these professional forecasts were investigated as possible methods to increase forecast utility and reliability. These methods are shown in Table 1 as methods 9 through 13.

The comparative forecast (method 10) was prepared by comparing the probabilistic forecast to the actual rainfall record for corresponding days. For each level of daily forecast, the weather record was checked for that day to see if rain had occurred. The number of rainfall events for each forecast level was divided by the total number of occurrences of each forecast level to determine the comparative probabilistic forecast.

The conditional comparative probabilistic forecast (method 11) was prepared by: 1) assuming the conditional portion of the analysis is represented by whether the probabilistic forecast was above or below a critical value, and 2) then noting the number of rainfall occurences in the total number of opportunities. The critical forecast value used in this study was 30%. Any forecast for greater than 30% could be thought of as a forecast for wet weather, otherwise it was considered as a dry weather forecast. All forecasts at 0%, 10%, 20%, and 30% were one conditional category. Forecasts for greater than 30% were the second conditional category. The rainfall record was examined to determine the number of times rainfall occurred in each of these two categories. The conditional probability was calculated by dividing the number of occurrences of rainfall by the number of categorical occurrences for each respective case. In this instance, the probability of rainfall, given that the forecast was 30% or less, was 0.190 while the probability of rainfall was 0.508, if the forecast was given as 40% or greater.

The comparative probabilistic forecast with a critical rainfall value (method 12) was prepared in the same manner as the comparative probabilistic forecast except that rainfall was defined as being at least 0.635 cm in magnitude. The conditional comparative probabilistic forecast with a critical rainfall value (method 13) was prepared using the procedure described for the conditional comparative probabilistic forecast except that rainfall was defined to be at least 0.635 cm in magnitude. The perfect forecast was prepared by examination of the rainfall record for 1984 through 1987. For any day that a rainfall event occurred, a probability of one was recorded. If no rainfall occurred, a zero probability was entered into the record.

For each irrigation scheduling method, which includes the methods identified from Harris (1981) and the C/L risk analysis method using ten estimates of rainfall probability, four years of production were simulated. Simulation trials were conducted at two levels of net irrigation application and three levels of irrigation cost to crop value ratios.

RESULTS AND DISCUSSION

Economic return is the primary concern for most agricultural producers. Net return is often defined as return to land, labor, and management. However, in this instance, return was defined as the income generated by the value of the crop yield minus the single operating cost of irrigation pumping energy. Total seasonal net irrigation was referred to as total irrigation application or irrigation water application.

Statistical Analysis of Return and Total Net Irrigation Application

An analysis of variance test was performed on return and total irrigation application data. Years, net irrigation application, method of irrigation scheduling, and all interactions were included in the statistical model, and tests for statistically significant differences were performed using a 5% confidence level. The statistical analysis grouped the four years based on rainfall amounts. The years of 1984 and 1985 were relatively dry, with rainfall amounts of 9.4 cm and 16.8 cm, respectively. The years of 1986 and 1987 were relatively wet with rainfall amounts of 20.6 cm and 26.3 cm, respectively. This grouping of years allows an estimate of the effect of years to be made.

SORGF is a deterministic model, so only single data points of yield can be generated for a given set of parameters. However, altering any input parameters results in an independent decision-making process. Obviously, the analysis could be strengthened with additional data, but was limited to four years because of the availability of professional forecast records.

Effects Due to Grouping of Years

The complete statistical model indicated that a difference in returns between the grouped years was apparent at each level of C/L ratio. Differences due to yearly effects are expected. However, in this instance, dry years had greater average return than wet years. This indicated that rainfall was not the only production factor involved. Irrigated crop production should tend to diminish the effect of rainfall differences between years, but many other production factors such as plant population, temperatures, and rainfall distribution, play a role. An important difference between years was the planting date, particularly for 1986 when a late planting date occurred. The lowest yield levels occurred in 1986.

Total irrigation application was also dependent on years. As logically expected, dry years had higher total irrigation applications than wet years.

Further statistical observations concerning the effect of net irrigation application and method of scheduling on return were clouded by the differences due to the grouping of the years. However, the irrigation scheduling procedure is not inherently dependent on whether the year is wet or dry because the decision to irrigate is made on a daily basis, using the current day's factors such as rainfall probability and soil water availability. The statistical analyses completed separately on the wet years and the dry years indicate the same tendencies shown by the full statistical model analysis. The data for wet and dry year analyses are not shown but are available in the original work by Rogers (1988). All significant differences from the full statistical analyses are noted in Table 2, regardless of significant difference detection based on years.

Net Irrigation Application

Net irrigation application causes statistically significant differences in return only in the high irrigation cost/low crop value ratio, with the 2.5 cm net application having the higher mean return. The 7.5 cm net application applied significantly more irrigation water than the 2.5 cm net application for all three C/L ratios. The model could not interrupt an irrigation once initiated. This meant the 7.5 cm net application had fewer decision points within a growing season once irrigated started. Consequently, there was less opportunity to take advantage of large rainfall events that might occur during an irrigation interval. The smaller net irrigation application was able to incorporate the event into its decision-making process earlier. The smaller net application also provided more opportunities to make incorrect decisions (i.e., failing to initiate an irrigation). However, incorrect decisions for one day result in only minimal damage, since a correct decision could be made the following day.

Scheduling Method

No significant differences in return were noted due to scheduling method for any of the C/L ratios. The perfect forecast did not distinguish itself from the other forecast methods. The perfect forecast always made correct decisions by delaying irrigation on days with rainfall. However, the relatively high frequency of very small rainfall events made many of the delay decisions essentially incorrect, since small rainfall events do not

TABLE 2. Summary of statistically significant differences for return and total irrigation application for a grain sorghum simulation trial

A: C/L Ratio: Low Irrigation Cost/High Crop Value

Significant Factor	Return $/ha	Significant Factor	Irrigation cm
Year:		Year:	
Dry	745.94	Dry	22.26
Wet	664.94	Wet	20.17
		Net Irr:	
		7.5	23.22
		2.5	19.21

B:C/L Ratio: Typical Irrigation Cost/Crop Value Ratio

Significant Factor	Return $/ha	Significant Factor			Irrigation cm
Year:		Year:			
Dry	327.62	Dry			19.92
Wet	293.07	Wet			17.13
		Net Irr:			
		7.5			20.52
		2.5			16.54
		Method:			
		GSO		A*	23.52
		GSI		A	23.52
		GS3		A	23.13
		GS13		A	22.74
		PERFECT	C	B	18.36
		CONDFCV	C	B	17.66
		CONDCV	C	B	17.66
		DAILYCV	C	B	17.66
		COMFCV	C	B	17.66
		FCST	C	B	17.50
		COND	C	B	16.10
		COMFCST	C	B	14.77
		DAILY	C	B	14.69
		CONDFCST	C		14.46

C: C/L Ratio: High Irrigation Cost/Low Crop Value

Significant Factor	Return $/ha	Significant Factor		Irrigation cm
Year:		Year:		
Dry	127.98	Dry		17.08
Wet	113.68	Wet		14.46
Net Irr:		Net Irr:		
7.5	115.89	7.5		17.38
2.5	125.78	2.5		14.15
		Method:		
		GSO	A*	23.52
		GS1	A	23.52
		GS3	A	23.13
		GS13	A	22.74
		COMFCV	B	13.69
		CONDFCV	B	13.69
		CONDFCV	B	13.67
		PERFECT	B	13.52
		FCST	B	13.36
		CONDFCV	B	13.28
		DAILYCV	B	13.28
		COMFCST	B	12.43
		CONDFCST	B	11.57
		DAILY	B	11.57
		COND	B	11.49

* Means with the same letter are not significantly different at the 5% confidence level

restore soil water depletions sufficiently to prevent yield limitations. The probabilistic forecast, and forecasts associated with a critical rainfall amount, tended to have returns as good or better than the perfect forecast.

There were significant differences in total irrigation application for the typical C/L ratio and the high irrigation cost/low crop value ratio. The stage of growth scheduling methods applied significantly more water than did the C/L methods. Stage of growth scheduling methods applied the same amount of water regardless of crop value to irrigation cost relationship. C/L methods limit water as water becomes more expensive relative to crop value.

Low Irrigation Cost/High Crop Value Analysis

Net return and total irrigation application for each scheduling method are shown in Table 3(A). The GS1 and GS0 had the highest return. The difference between GS1 and COMFCST, which had the lowest return, was $20.99/ha — a reduction of 3%. The growth stage scheduling methods, as a group, applied from 22.74 to 23.52 cm of water, slightly more than C/L methods which ranged from 19.92 to 20.55 cm. CONDFCST applied 15% less water than GS1.

Typical Irrigation Cost/Crop Value Analysis

Net return and total irrigation application for each scheduling method are shown in Table 3(B). The four stage of growth methods had the highest level of return. The C/L scheduling methods using FCST, PERFECT, and the forecasts associated with a critical rainfall value appeared to form a second group. The difference between GS1, highest return, and DAILY, lowest return, was $33.90/ha or about 10%.

All stage of growth methods applied a high level of irrigation water compared to C/L methods. The range of difference between FS1 and CONDFCST was 9.06 cm or about 39%. A difference in the total irrigation applied also appeared to exist within the C/L methods. Those with the lowest return also tend to apply the least amount of irrigation water.

High Irrigation Cost/Low Crop Value Analysis

Net return and total irrigation application for each scheduling method are shown in Table 3(C). The stage of growth methods had the highest return. The difference between GS1, highest return, and DAILY, lowest return, was $19.02/ha or 15%. The C/L scheduling methods associated with a critical rainfall value, along with PERFECT and possibly FCST, appeared as the next highest level of return.

Stage of growth methods clearly apply more irrigation water than C/L methods. The difference between GS1 and COND was 12.03 cm or 51%.

CONCLUSIONS

General Observations

Considering only return, stage of growth scheduling methods (especially GS0 and GS1) were superior scheduling methods. Stage of growth scheduling methods had highest returns for each of the C/L ratios; however, the difference between the highest and lowest return was not large.

The stage of growth scheduling methods are not affected by the C/L ratio and, consequently, apply an identical amount of irrigation water regardless of the ratio. The C/L methods applied decreasing water amounts with increasing C/L ratios. The C/L methods applied approximately half the amount of irrigation water that growth stage methods applied for the high irrigation cost/low crop value ratio. The tendency of the C/L scheduling methods to apply less water than growth stage methods is an important consideration when comparing C/L methods to stage of growth methods. For full irrigation programs, when irrigation costs are low relative to crop value, the growth stage method appears to be the better management choice. The C/L methods may be the better choice for scheduling when irrigation water is limited by supply or institutional constraints, and/or when irrigation costs are high relative to crop value. The C/L methods associated with critical rainfall values and the probabilistic forecast appeared to have

TABLE 3. Average return and total irrigation application from a grain sorghum simulation trial

A: C/L Ratio: Low Irrigation Cost/High Crop Value			B: C/L Ratio: Typical Cost/Crop Value			C: C/L Ratio: High Irrigation Cost/Low Crop Value		
Method of Scheduling	Return $/ha	Irrigation cm	Method of Scheduling	Return $/ha	Irrigation cm	Method of Scheduling	Return $/ha	Irrigation cm
GS1	719.09	23.52	GS1	326.61	23.52	GS1	130.38	23.52
GSO	718.79	23.52	GS0	326.47	23 52	GS0	130.31	23.52
GS13	707.65	22.74	GS13	322.00	22.74	GS13	129.17	22.74
COMFCV	706.17	20.55	GS3	319.75	23.13	GS3	127.50	23.13
DAILYCV	705.21	20.55	FCST	312.17	17.50	CONDCV	122.57	13.67
CONDFCV	705.19	20.55	CONDCV	312.11	17.66	COMFCV	121.07	13.69
CONDCV	704.95	20.63	COMFCV	312.08	17.66	PERFECT	120.73	13.52
GS3	704.25	23.13	DAILYCV	311.49	17.66	CONDFCV	120.35	13.28
PERFECT	703.21	20.55	PERFECT	311.27	18.36	DAILYCV	120.35	13.28
FCST	702.93	20.39	CONDFCV	311.08	17.66	FCST	118.84	13.36
COND	701.39	20.63	COMFCST	298.64	14.77	COMFCST	114.21	12.43
DAILY	699.73	20.24	COND	295.35	16.10	COND	113.44	11.49
CONDFCST	699.44	19.92	CONDFCST	293.10	14.46	CONDFCST	111.36	11.57
COMFCST	698.10	20.08	DAILY	292.71	14.69	DAILY	111.36	11.57

better returns than the C/L methods using other forecasts and to have less total irrigation application than any stage of growth method.

Statistical Analysis

No differences in return due to scheduling method were indicated for any of the three C/L ratios. The analysis indicates that return was dependent on years. The difference due to years was expected since each year has unique production influences. The decisions for both growth stage and C/L methods were made on a daily basis. This means the overall yearly effect on production had no direct influence on the daily decision. Conclusions drawn disregarding yearly differences were the same as conclusions drawn from within year comparisons.

Total irrigation application obviously varies with years. However, as with return, the difference due to years was negated by the daily decision-making process. Growth stage scheduling methods applied significantly more water than the C/L methods for typical and high irrigation cost/low crop value ratios.

Net irrigation application was identified as having an effect on total seasonal irrigation application at all C/L levels. This effect is reasonable, regardless of scheduling method, since a smaller net application amount provided more opportunities to make decisions based on the scheduling criteria. The opportunity to make more irrigation decisions for the 2.5 cm net application offsets a potential disadvantage of having more evaporation due to more frequent irrigation application. The C/L risk analysis scheduling method was used successfully for each net application amount and could be used for any system type, if proper accounting of costs associated with irrigation system occurs.

SUMMARY

The C/L risk analysis decision-making process has merit in determining irrigation schedules. Returns from the C/L methods are not statistically different from growth stage methods used to represent improved irrigation scheduling practices. However, C/L methods clearly apply less irrigation water for increasingly adverse C/L ratios. Since little or no reduction in net return to the producer occurs, the C/L scheduling method may be of great value to an irrigator with total water application limitations due to either source of supply or institutional constraints.

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