Optimal irrigation schedules and estimation of corn yield under varying well capacities and soil moisture levels in Western Kansas

Sreedhar Upendram and Jeffrey Peterson

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meetings, Orlando, Florida, February 5-8, 2006

January 2006

Abstract

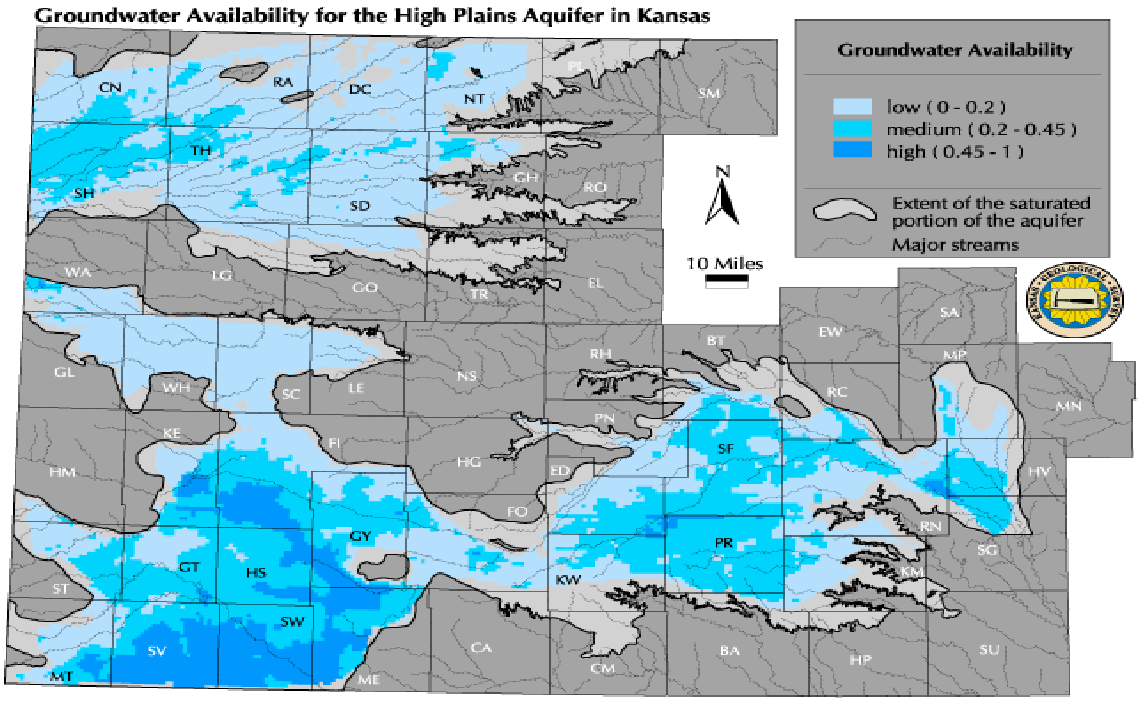
Irrigation scheduling helps in maintaining optimal soil moisture and conserving water. In this paper, we simulate corn yields for alternative irrigation schedules under varying well capacities and soil moisture levels. The simulated yields are then used to generate probability distributions of net returns, which are evaluated using stochastic dominance.

Introduction

Water is the elixir of life. Water is a scarce resource with competing demands – drinking, irrigation, industrial and recreational uses. Irrigation is by far the largest demand of water among the competing uses in many semi-arid agricultural regions such as the Great Plains. In Western Kansas, the groundwater supplies are declining at an alarming rate because more water is pumped out for irrigation than the rate at which the aquifer is recharging, which is leading to acute water shortage. The groundwater availability for the Ogallala aquifer in Western Kansas is illustrated in Figure 1.

Due to water shortage, crop plants undergo severe water-stress which might affect yields. Irrigation scheduling is a viable solution technique for systematically determining the time and quantity of irrigation in individual fields where there is water shortage. By scheduling irrigation, producers can maintain the soil moisture above permanent wilting point levels and conserve water by avoiding unnecessary irrigation events. On the other hand, crops that are less water-intensive and dry-land crops can be grown in areas where there is severe water shortage.

Figure 1. Groundwater availability for the Ogallala aquifer in Western Kansas



Source: Kansas Geological Survey.

In this paper, we simulate corn yields for alternative irrigation schedules under varying well capacities and soil moisture levels. The simulated yields are then used to generate probability distributions of net returns, which are evaluated using stochastic dominance. The paper is organized as follows: we introduce the objectives, state assumptions, briefly describe the data and analysis – Irrigation scheduling, yield estimation, comparison of net returns; discuss the results and draw conclusions.

The two main objectives of this research are to

1. Estimate corn yield under varying well capacities and soil moisture levels.
2. Determine optimal irrigation schedules for different risk preferences.

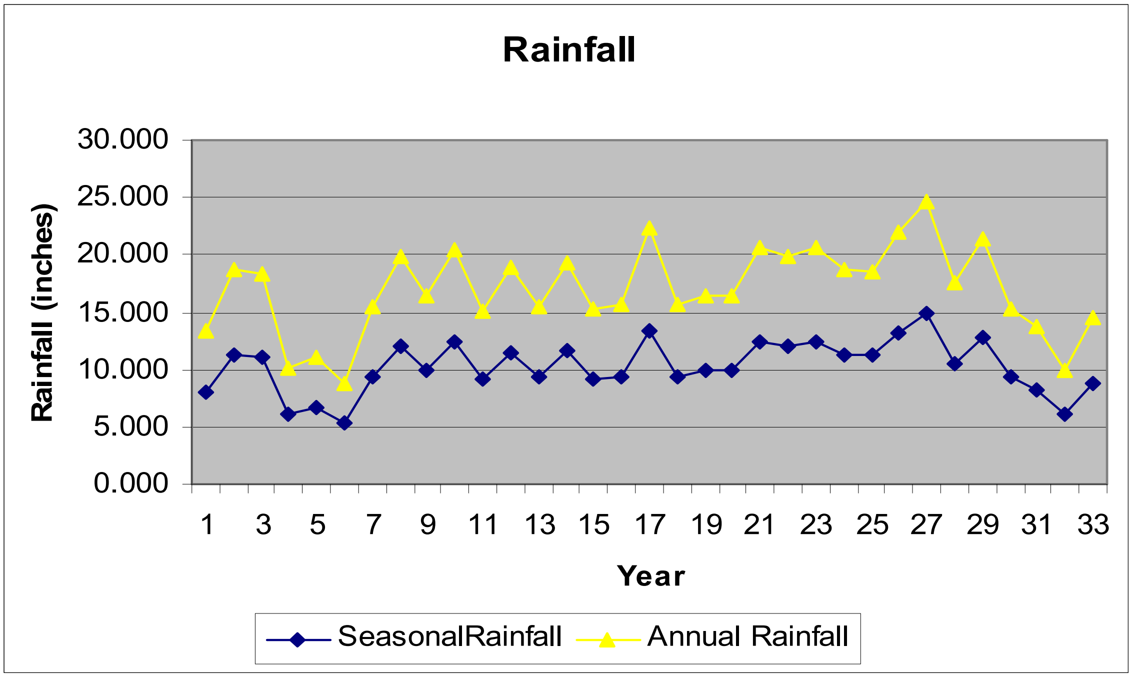
Assumptions

For the purpose of analysis we assumed that the farmer owns the land, machinery and equipment. We assumed that a fixed acreage is irrigated using a standard seven tower center pivot irrigation system and the irrigation efficiency of the system is 85%. The farmer is assumed to have risk-averse preferences. We also assumed that the farmer chooses one of the management allowed deficit (MAD) levels of 0, 0.15, 0.30, 0.45 and 0.60 at the beginning of the season to trigger an irrigation event as the season progresses. In other words, if the soil moisture goes below the MAD level, an irrigation event is triggered. We assumed three irrigation well capacities – 280, 400 and 699 gallons per minute (gpm) wells and three initial soil water availability levels - 0.45, 0.65 and 0.85, corresponding to the well capacities. We limited the number of irrigations during the crop season to 18 due to a limitation inherent to the Kansas Water Budget (KWB) model. Water regulations in Western Kansas limit the total amount of irrigation to 24 inches during the crop season.

Data

In the analysis of this paper, we used long-run weather data obtained from the Kansas Weather Data Library for Tribune, Kansas comprised of daily observations of temperature, rainfall, solar radiation for the years 1971-2003. Using the long-run weather data for 33 years, we created a similar distribution of rainfall for the crop season from May 15 – September 5. The rainfall distribution is illustrated in Figure 2.

Figure 2. Seasonal and Annual Rainfall Distribution



We obtained long-run evapo-transpiration values and crop coefficients from the KWB model for the crop season (May 15 - September 5). The cost of production was computed using crop enterprise budget developed by K-State Research and Extension. The price of natural gas was obtained from the Department of Energy and the price of corn was obtained from Ag Outlook.

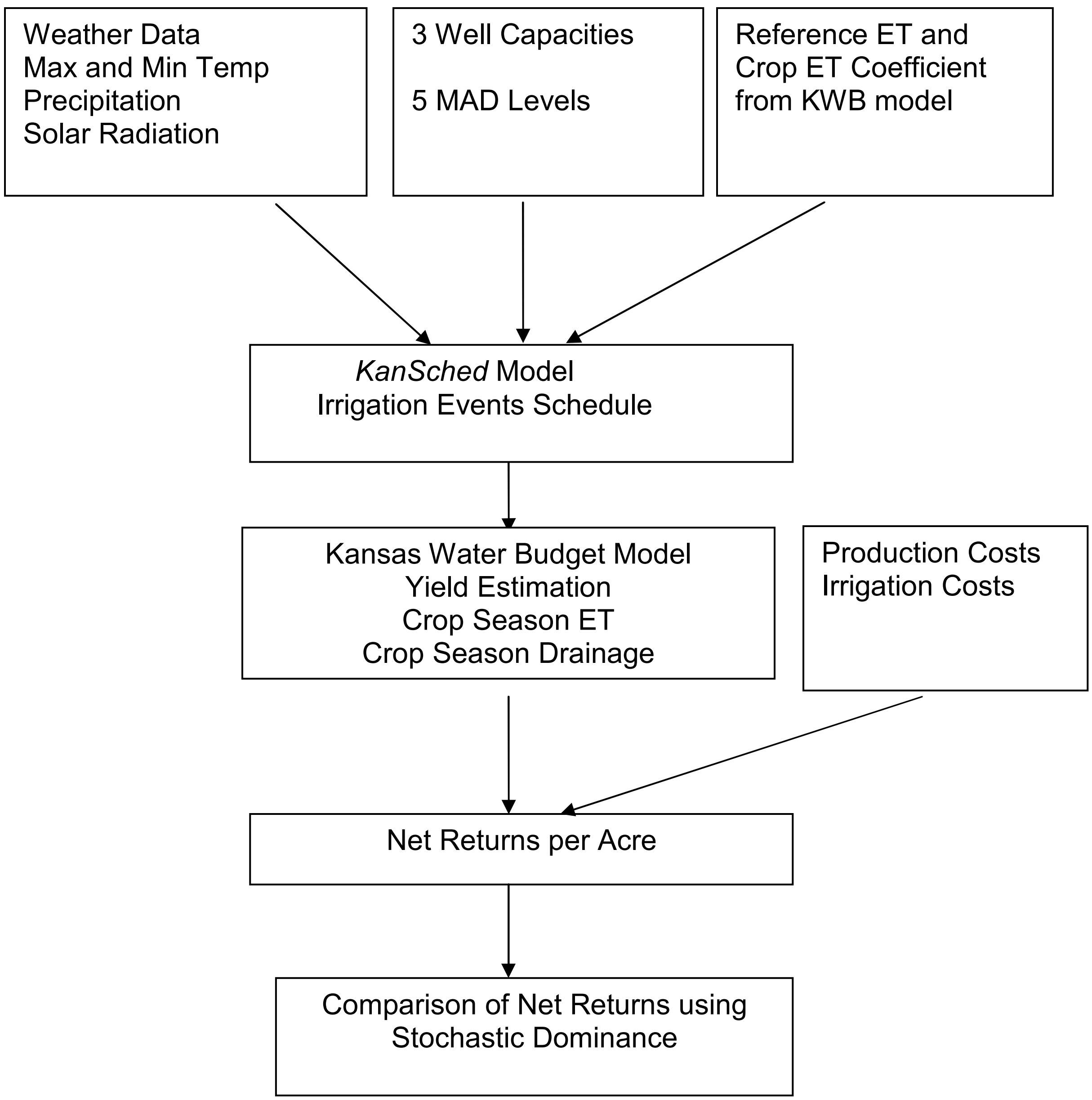
Irrigation events were scheduled using the *KanSched* model (Clark and Rogers). Table 1 presents the input information required to run the *KanSched* model. We set the soil water holding capacity to 0.15, permanent wilting point to 0.13 representing the Ulysses silty loam soil type in Tribune, Kansas. The emergence date for corn based on the long-run average data was set to May 15. The water budget start date was set four weeks after the emergence to June 15 because there is enough moisture in soil to sustain plant growth from May 15- June 15. The water budgeting ended after the crop matured, 113 days after emergence i.e. on September 5. The depth of the roots on the start date for corn was set at 6 inches and the maximum root zone depth that would be able to pull water from the soil profile was set at 24 inches. The crop growth dates correspond to irrigated corn in Western Kansas. The crop coefficients were adjusted to fit the crop coefficients from the KWB model as closely as possible.

Table 1. General Input Information for *KanSched* model

General Input Information	**Data**
Soil Available Water Holding Capacity (inches of water/inch of soil depth)…………	**0.15**
Enter the Permanent Wilting Point (PWP) water content of the soil (in./in.)…………	**0.13**
Emergence Date (for example, enter June 1 as 6/1)……………………………	**15-May**
Enter the Date To Start The Water Budget for the crop.	**15-Jun**
Enter the root depth (inches) on the start date (for example 6 inches and must be >1)	**6**
Enter the maximum managed root zone depth in inches (the range is from 12 to 48 inches)	**24**
Enter the date that the crop canopy cover exceeds 10% of the field area (e.g. 6/15/00) [This is the date that rapid growth begins]	**4-Jun**
Enter the date that the crop canopy cover is at 70% to 80% of the field area (e.g. 6/25/00)	**8-Jul**
Enter the date when the crop is at initial maturation (water use is declining, e.g. 8/1/00)	**16-Aug**
Enter the date of the end of the growing season (e.g. 8/25/00)……………	**22-Sep**
Enter the initial crop coefficient (0.25 is the default)………………………	**0.28**
Enter the maximum crop coefficient (1.00 is the default)………………………	**1.07**
Enter the final crop coefficient (0.6 is the default)………………………………	**0.34**

The sequence of analysis is presented as a flowchart in Figure 3. The flowchart illustrates the data used in the analysis, the input information required for each model and the output obtained from each model. The flowchart depicts the sequence of irrigation scheduling using *KanSched*, yield estimation using KWB model and comparison of net returns using stochastic dominance approach.

Figure 3. Model Flowchart of Irrigation Scheduling, Yield Estimation and Comparison of Net Returns



Irrigation Scheduling

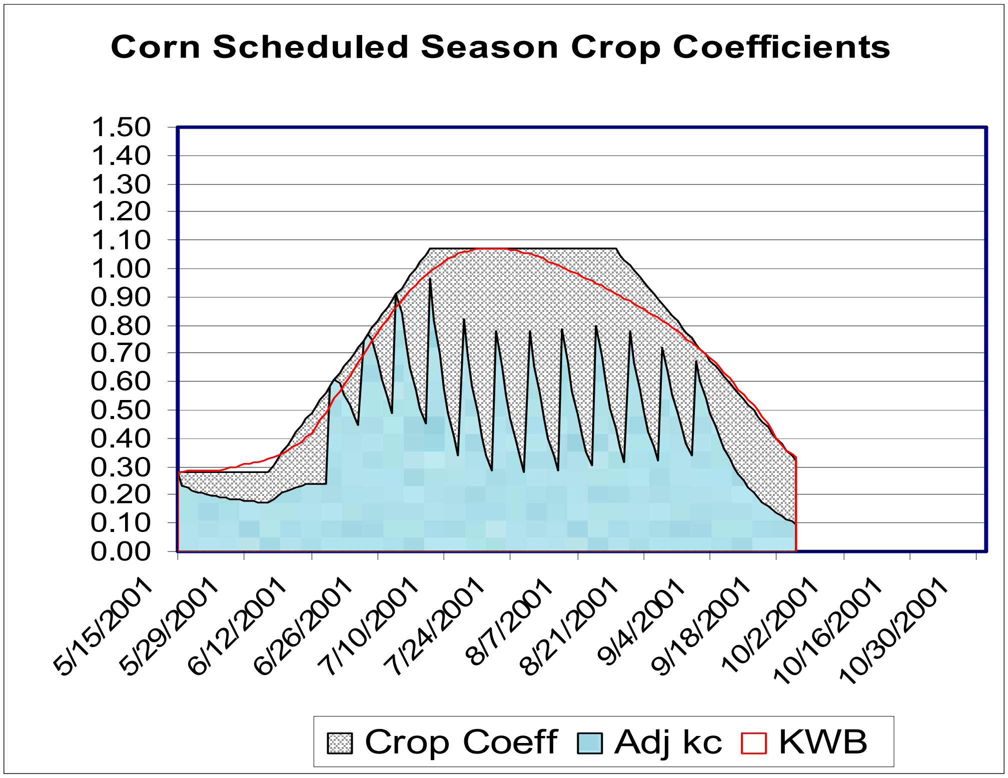
The rainfall, ET and crop coefficient data for the period of the crop season i.e. from May 15- September 21 was obtained from the KWB model. The *KanSched* model monitored the water balance in the soil and scheduled irrigation based on daily values of rainfall and ET. The crop coefficient values were set to fit the crop coefficient values closely. An irrigation event was triggered whenever the soil moisture fell below a threshold value known as the management allowed deficit (MAD). Irrigation schedules for corn corresponding to three well capacities (280, 400 and 699 gallons per minute) and five MAD values (0, 0.15, 0.3, 0.45 and 0.6) were computed using the *KanSched* model. Table 2 presents the irrigation capacity, frequency, flow-rate and initial soil water availability for each well capacity.

Table 2. Irrigation Capacity, frequency, flow-rate and Initial soil water availability for a standard Seven Tower Center Pivot 1" Net Irrigation to make a complete revolution irrigating 126 acres at various well capacities.

Irrigation Capacity Inches per day	**Frequency and Amount Applied**	**Flow-rate in GPM**	**Initial Soil water availability**
0.100"	1" in 10 days	280	0.45
0.143"	1" in 7 days	400	0.65
0.250"	1" in 4 days	699	0.85

In addition to scheduling irrigation, the *KanSched* model plots a graph based on the crop coefficient and ET values against the crop growth season. The graph traces out a piece-wise linear graph from the values of crop coefficient values, adjusted crop coefficient and the crop coefficient value from the KWB model. Figure 4 illustrates the three crop curves - the piece-wise linear curve represents the crop coefficient, the curve with peaks and troughs represents the adjusted crop coefficient and the smooth red line represents the crop coefficient from the KWB model.

Figure 4. Corn Season Crop Coefficient Curves



Yield Estimation

The yields for corn were simulated using the KWB model developed by Stone *et al* (1995). In particular, the KWB model predicted corn yields from each irrigation schedule using daily observations of rainfall, irrigation, temperature and solar radiation. We specified the number of irrigations and annual rainfall in KWB model and used the irrigation schedule obtained from the *KanSched* model to simulate yields in the KWB model. The corn average yields and irrigation events are presented in Table 3. The KWB model simulated yields were based on Alfalfa reference ET and generated a detailed report of ET, drainage and yields.

Table 3. Corn Average Yields and Average Number of Irrigation Events by MAD

	280 GPM		400 GPM		699 GPM	
MAD	Average Yield	Average Irrigation	Average Yield	Average Irrigation	Average Yield	Average Irrigation
	Bushels/ Acre	Inches	Bushels/ Acre	Inches	Bushels/ Acre	Inches
0	147.78	9	184.53	12	224.67	18
0.15	147.69	9	183.08	12	223.47	17.88
0.3	136.17	8.12	175.22	11.21	212.48	15.03
0.45	132.26	7.88	171.02	10.88	207.85	14.42
0.6	122.05	7.18	156.24	9.52	169.29	10.33

The average yields for corn increased as the irrigation well capacity increased from 280 gpm to 699 gpm. The average yields for corn decreased as the level of MAD increased from 0 to 0.6 for each well capacity. The average number of irrigations decreased as the MAD level increased for each well capacity. The decrease in average number of irrigations was higher for 699 gpm well, intermediate for 400 gpm well and lowest for 280 gpm well. The average yields for corn for by MAD level and average net returns by well capacity are illustrated in Figure 5 and 6, respectively. The well capacity and MAD level appear to be similar because the values of net returns and yields are averaged over 33 years.

Figure 5. Corn Average Yields by MAD Level

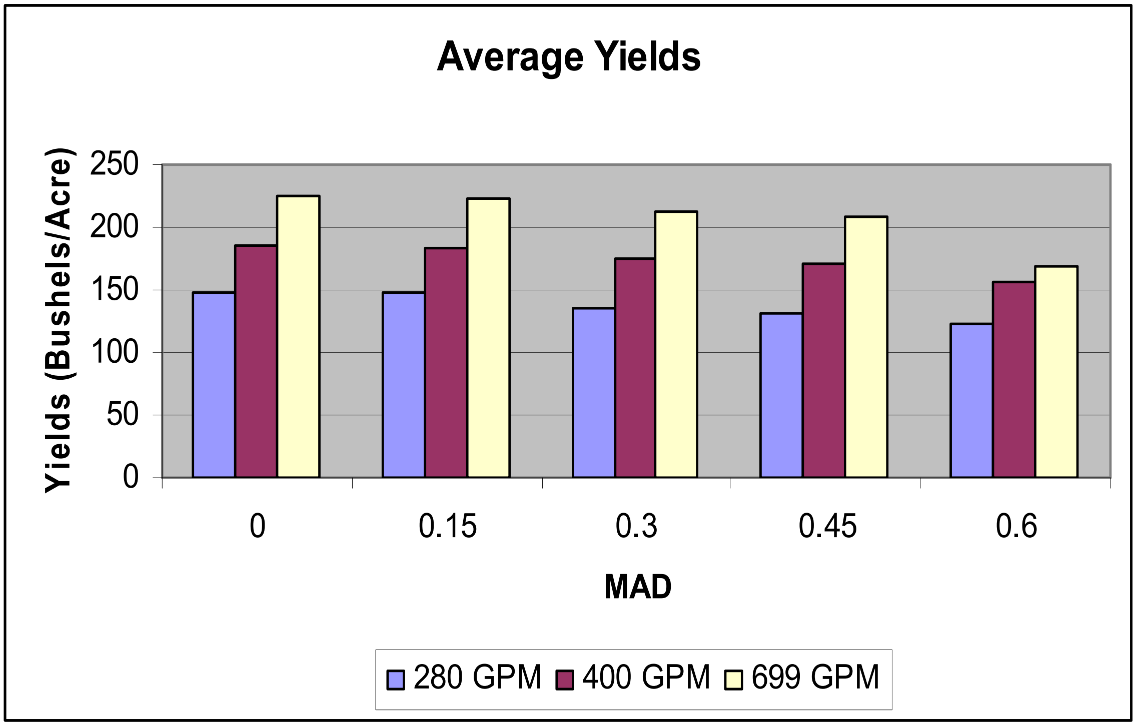
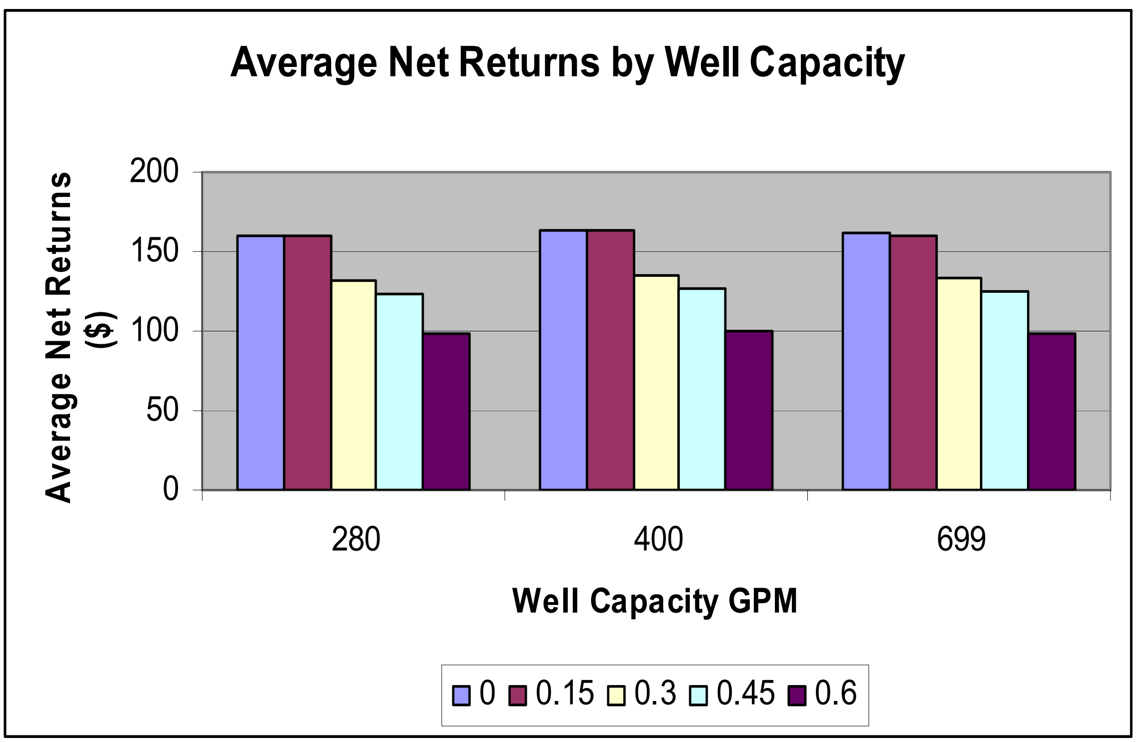


Figure 6. Average Net Returns by Well Capacity



Comparison of Net Returns

The simulated yield and K-State Extension projected crop budgets were used to compute net returns for each year in the weather dataset, specified MAD and well capacity. Finally, the simulated net returns were grouped to form a probability distribution for corn and the distributions were ranked using SDRF (Stochastic dominance with respect to a function) in *SIMETAR*. To compare the net returns from the three well capacities under five MAD levels, we set the 0 MAD level as the base alternative and chose a range of risk aversion coefficient of 0 – 0.619. The upper bound for the risk aversion coefficient was determined based on methods described by McCarl and Bessler. This method multiplies the expected value by two and divides by the variance for each probability distribution. Using this method, the maximum RAC estimate was found to be 0.619. The CDF distributions for 280, 400 and 699 gpm well capacities are presented in Figures 7, 8 and 9, respectively.

Figure 7. CDF distribution for 280 gpm well for 5 MAD levels

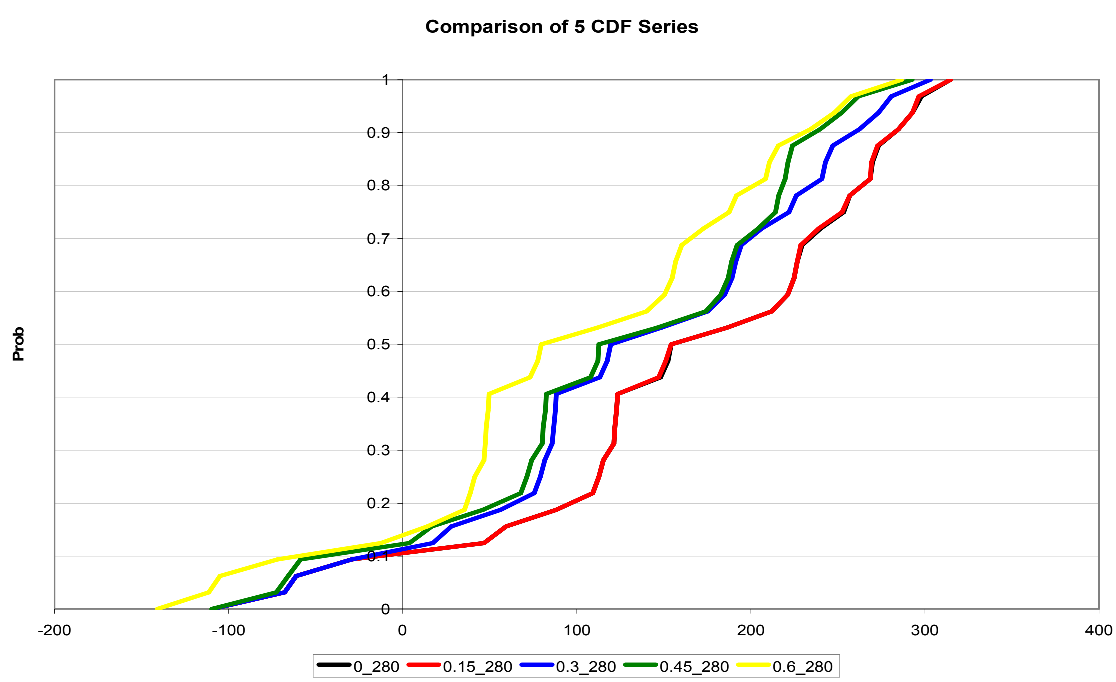


Figure 8. CDF distribution for 400 gpm well for 5 MAD levels

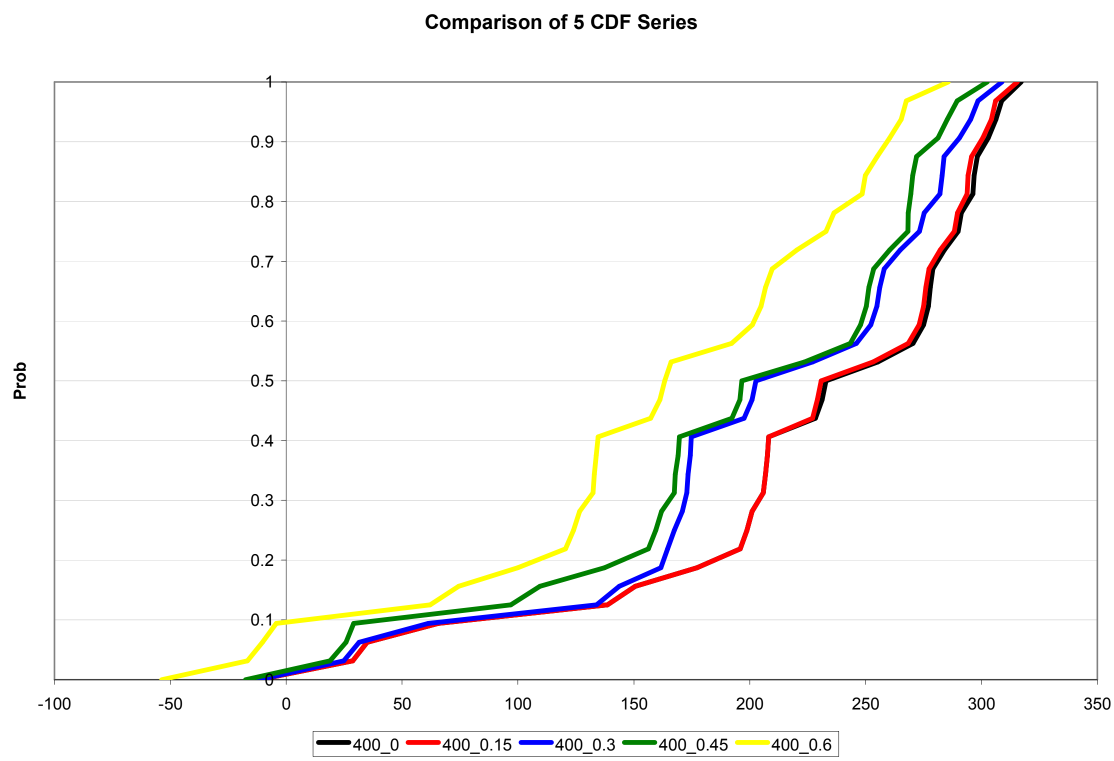
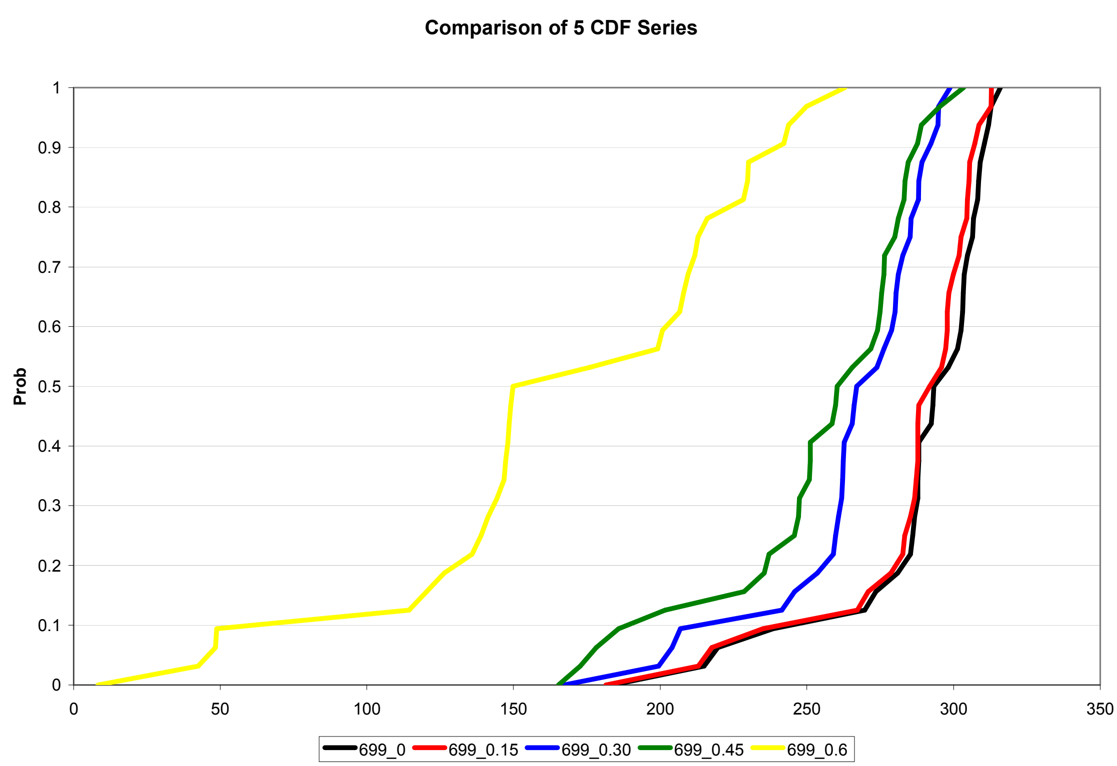


Figure 9. CDF Distribution for 699 gpm well for 5 MAD levels



The net returns distributions comparing the MAD levels for each well capacity indicates that the highest net returns for all the three well capacities was obtained when the MAD was set to 0. The net returns decreased as the MAD level increased from 0 to 0.6. The net returns distribution had a smaller spread for 280 gpm well, but the gap between the distributions widened as the well capacity increased. This indicates that the MAD has a greater effect on the net returns at the higher well capacities than at the lower well capacities. Further, the slope of the net returns distribution for the lower MAD levels increased as the well capacity increased.

The stochastically dominant well capacities under a risk aversion coefficient of 0.399 are presented in Table 4. The 0 MAD level was the most preferred MAD and 0.60 MAD level was the least preferred for each well capacity and the preference level decreased as the MAD level increased from 0 to 0.60 for each well capacity.

Table 4. Stochastically dominant well capacities under RAC of 0.619

280 GPM	**0.619 Upper RAC**	**400 GPM**	**0.619 Upper RAC**	**699 GPM**	**0.619 Upper RAC**
0	Most Preferred	0	Most Preferred	0	Most Preferred
0.15	Most Preferred	0.15	Most Preferred	0.15	2nd Most Preferred
0.3	3rd Most Preferred	0.3	3rd Most Preferred	0.45	3rd Most Preferred
0.45	4th Most Preferred	0.45	4th Most Preferred	0.3	4th Most Preferred
0.6	Least Preferred	0.6	Least Preferred	0.6	Least Preferred

For the 280 gpm well capacity, since the net returns for 0 and 0.15 MAD level were very close to each other, both 0 and 0.15 MAD levels were the most preferred. In the case of 699 gpm well capacity, 0.45 MAD level was preferred to 0.30 MAD level because there are unnecessary irrigations at the 0.30 MAD level that are not yielding any higher yields. This stresses the importance of choosing the optimal MAD for each well capacity to maximize the net returns and conserve water.

Summary and Conclusions

In this paper, we scheduled irrigation for corn using weather data and evapo-transpiration under variable well capacities, MAD level and initial soil water availability levels in the *KanSched* model. We used this irrigation schedule to simulate corn yields under variable rainfall conditions and computed net returns. The net returns for each well capacity were compared to determine the optimal MAD level for each well capacity. The 0 MAD level was the most preferred whereas the 0.60 MAD level was the least preferred at each well capacity. The effect of MAD level on net returns was higher for higher well capacities. By adjusting MAD level, we can avoid unnecessary irrigation events and increase net returns while conserving water. Anecdotal evidence suggests that farmers irrigate using an MAD level of 0.5, but our results suggests that the farmers are altruistic because they are using less than optimal amount of water for irrigation, thereby, saving water for future or alternative uses.

References

1. Bernardo, D.J., Whittlesey, N.K., Saxton, K.E., and Bassett, D.L., An irrigation model for management of limited water supplies, Western Journal of Agricultural Economics, Vol.12, No.2, December 1987, pp 164-173.
2. Bras, R.L., and Cordova, J.R., Intraseasonal water allocation in deficit irrigation, Water Resources Research, Vol.17, No.4, August 1981, pp 866-874.
3. Clark, G.A., and D. Rogers. "KANSCHED: An ET-Based Irrigation Scheduling Tool for Kansas Summer Annual Crops." Kansas State University Research and Extension, March 2000.
4. Doorenbos, J., and A.H. Kassam. "Yield Response to Water." Paper 33, Food and Agricultural Organization of the United Nations Irrigation and Drainage, Rome 1979.
5. Doorenbos, J., and W.O. Pruitt. "Guidelines for Predicting Crop Water Requirements." Paper 33, Food and Agricultural Organization of the United Nations Irrigation and Drainage, Rome 1977.
6. Dudek, D.J., Horner, G.L., and English, M.J., The derived demand for irrigation scheduling services, Western Journal of Agricultural Economics, December, 1981, pp 217-227.
7. Dumler, T.J., and C.R. Thompson. "Center-Pivot-Irrigated Corn Cost-Return Budget in Western Kansas." Farm Management Guide, Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Publication MF-585, Manhattan, Kansas, October 2005.
8. Feinerman, E., and Falkovitz, M.S., Optimal scheduling of nitrogen fertilization and irrigation, Water resources management, Vol.11, 1997, pp 101-117.
9. Harris, T.R., and Mapp, H.P., A Stochastic dominance comparison of water-conserving irrigation strategies, American Journal of Agricultural Economics, May 1986, pp 298-305.
10. Hornbaker, R.H., and Mapp, H.R., A dynamic analysis of water savings from advanced irrigation technology, Western Journal of Agricultural Economics, Vol.13, No.2, December 1988, pp 307-315.
11. Jones, H.G., Irrigation scheduling: advantages and pitfalls of plant-based methods, Journal of Experimental Botany, Vol.55, No.407, Water-saving Agriculture Special Issue, November 2004, pp 2427-2436.
12. Minhas,B.S., Parikh,K.S. and Srinivasan, T.N., Toward the structure of a production function for wheat yields with dated inputs of irrigation water, Water Resources Research, Vol.10,No.3, June 1974, pp 383-393.
13. Peterson, J.M., and Bernardo, D.J., A review of economic analysis or water policies and irrigation issues in the high plains: 1980-2000, Research report#36, Department of Agricultural Economics, Kansas State University, Manhattan, KS, June 2003.
14. Richardson, J.W., K. Schumann, and P. Feldman. "SIMETAR©: Simulation for Excel to Analyze Risk." Agricultural and Food Policy Center.

Department of Agricultural Economics, Texas A&M University, January 2004.

15. Stone, L.R., Buller, O.H., Schelgel, A.J., Knapp, M.C., Perng, J-I., Khan, A.H., Manges, H.L., and Rogers, D.H., Description and use of Kansas water budget vs. T1 software, Resource Manual, Department of Agronomy, Kansas State University, Manhattan, KS, December 1995.
16. Talpaz, H., and Mjelde, J.W., Crop irrigation scheduling via simulation-based experimentation, Western Journal of Agricultural Economics, Vol. 13, No.2, December 1988, pp184-192.
17. Yaron, D., Bresler, E., Bielorai, H., and Harpinist, B., A model for optimal irrigation scheduling with saline water, Water Resources Research, Vol. 16, No.2, April 1980, pp 257-262.