2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

ANALYSIS OF SITE-SPECIFIC IRRIGATION WITH GOSSYM SIMULATION MODEL

R.W. Clouse and S.W. Searcy
Biological and Agricultural Engineering Department
Texas A&M University
College Station, TX

Abstract

Development of site-specific irrigation systems requires tools and techniques for making decisions with the increased management complexities that these systems cause. Crop simulation models represent a quick and efficient way to evaluate potential management alternatives. Effects of different irrigation application rates on a hypothetical field comprised of two soils with equal areas were evaluated in this study. The situation examined was for the Texas High Plains cotton growing region. Differences in yield response for the different soils led to increases in overall field yield for site-specific irrigation as compared to uniform irrigation. Increases in yield would increase revenue from the field, which is a potential reason for implementing a site-specific irrigation system. Yield increases did not occur in each simulation year, thus anticipated revenue increases would need considered over a period of several years.

Introduction

Site-specific crop management (SSCM) involves the management of fields at areas smaller than that of the entire field. SSCM implementation has primarily involved fertilizer management. Reasons for this development include development of effective application technologies, the cost of fertilizers and the potential for more efficient usage of fertilizers. Site-specific application of inputs other than fertilizers is technically feasible. Water is a vital component of crop growth. Simulation studies have attributed over 50% of observed crop yield variability with water-related soil parameters (Paz et al., 1998). Thus from a management perspective, water inputs should be managed in a site-specific manner. Research on implementation of site-specific traveling irrigation systems has occurred in Washington state (Evans et al., 1996), Georgia (Perry et al., 2002), and South Carolina (Camp et. al., 1998), among others, on crops including potatoes, peanuts, and corn.

Cotton grown in the High Plains of Texas represents an opportunity for the implementation of site-specific irrigation systems. Much of the cotton grown here is under traveling irrigation systems which would allow for implementation of site-specific management without large amounts of labor. Water usage from agriculture in this region is also a critical issue due to the steady declines in the Ogallala aquifer over the past decades. Wells in this area may pump at levels below that of crop water usage, thus causing deficit irrigation. The ability to adjust water applications across a field with site-specific irrigation could potentially conserve and/or use the water resources of this area more efficiently.

Effective implementation of site-specific irrigation systems will require knowledge of the effects of different management strategies on crop yield. Crop simulation models are tools that would allow for relatively fast evaluation of alternative management strategies on cropping systems. These models are mathematical representations of the factors that affect plant growth processes. Factors represented in them include effects of water, fertilizers, weather, and management practices. These factors are also important for reflecting variability that occurs in crop yield across fields, thus these models are potentially useful tools for site-specific management. The GOSSYM crop simulation model (Baker 1983) is a crop-specific model for simulating cotton growth. The development, validation, and applications of this model are outlined in Reddy et al. (2002).

The goal of this paper is to examine effects of site-specific and uniform irrigations on a hypothetical farm field through the usage of a crop simulation model. The scenarios to be examined involve two soil types of equal size in the field. Simulations of crop yield and water usage for multiple application levels will be made using multiple years of historical weather data.

Methodology

The site-specific situation examined in this paper represents a hypothetical field composed of two soils located in Lubbock County, Texas. Growing seasons from 1995 through 2001, with the exception of 1996 were simulated. Lubbock County is part of the largest cotton producing region in the state of Texas. Typically it ranks among the top 5 counties in cotton acreage planted each year (Texas Agricultural Extension Service, n.d.). An Amarillo loamy fine sand and Olton clay loam soil were used in the simulations. These soils are two of the three most common soils in Lubbock County and can be found adjacent to each other in portions of the Amarillo-Acuff mapping unit (United States Department of Agriculture, Soil Conservation Service 1979). The soil profiles used in the simulations was from the soils database included with the GOSSYM model. Differences in the soils can potentially indicate the need for different management needs across a field where these soils occur.

Five different application rates were applied to both soil types at fixed times during the growing season. A fixed interval schedule was utilized to allow for consistent decision-making between the different soils. The dates on which irrigations were applied are presented in Table 1. The irrigations are applied on a weekly basis between June and August when the water needs of the plants are greatest and once during May when water needs are smaller. Daily irrigations were adjusted so that the sum of a scheduled irrigation and the rainfall over the four previous days did not exceed 1.5 inches.

Five water levels, 1.5, 1.0, 0.6, 0.5, and 0.4 inches were applied to both soils. Uniform water applications can subject various parts of fields to over and under- water applications depending on the management strategy used. The water levels selected allow for evaluation of the maximum yield potential of the field and the yield response that might occur under different management schemes. Since pumping rates in the High Plains region fail to meet the plant water usage rates, the 0.5 inch application rate is of particular interest for irrigation in this area. Water application rates of 0.4 inches and 0.6 inches were applied to each soil type to evaluate how varying irrigation from a uniform rate of 0.5 inches might affect crop yield. A common practice in the High Plains is to apply a pre-plant irrigation to fields. To examine the effects of pre-plant irrigations on yields, simulations were made with initial soil water levels in the top soil layers at 95% and 50% of field capacity. For the 50% case, the soil water level was gradually varied up to 95% at a depth of 48 inches.

Version 3.0 of GOSSYM was used for the simulations. Weather data from the South Plains Evapotranspiration Network (http://lubbock.tamu.edu/irrigate/et/etMain.html n.d.) was utilized. In the simulations, adequate nitrogen was applied so that no nitrogen stress occurred in the model runs. Additional inputs for the GOSSYM model that represent the management scenario in the simulation appear in Table 2.

Discussion

Irrigation totals and cotton yield for the five water application rates and two initial soil water levels appear in Tables 3, 4 and 5, respectively. Climatic effects on the yield results are evidenced by the large variations from the mean yield values for individual years. For instance, for the 1998 weather data, the Amarillo soil, and a 95% full initial soil profile, the model predicted a yield of 1780 lbs./acre. This yield value is 465 lbs./acre larger than the average simulated yield over all six years of 1315 lbs./acre. In some cases, yearly differences in yearly yield from the mean yield values can be explained by examining the yearly climactic data shown in Figures 1 and 2. In this case, the most apparent explanation of the higher than average yield in 1998 is the above average temperatures during May, June, and July.

Yield response curves of the average yield for the five application rates and two beginning soil water levels are shown in Figure 3. The yield response curve for the Olton soil is nearly flat across all five application rates and beginning water levels. The Amarillo soil has a steep response curve between the 0.5 inch and 1.0 inch application rates for the 95% beginning soil water level and between the 0.5 inch and 1.5 inch application rates for the 50% beginning soil water level. The Amarillo soil's need for more irrigation water to promote crop yield is expected for a soil that is relatively sandy. Likewise the clay loam Olton soil retains water better, therefore needs less applied water to produce higher crop yields. These results indicate that in a site-specific irrigation situation at the lower application rates, adding water to the Amarillo soil should produce higher yields from a field as a whole.

With a site-specific irrigation system in a deficit irrigation situation, the uniform application rate of 0.5" could be replaced by rates of 0.4" and 0.6" on the two different soils. The rates for the site-specific situation were one combination of many possible that average out to 0.5" which could be tested. Yield results for the two soils individually at these irrigation application rates are shown in Tables 6 and 7. Yields for a field with equal areas of the two soils for the uniform and site-specific cases are shown in Tables 8 and 9. By applying 0.1" more water to the Amarillo soil and 0.1" less water to the Olton soil, the average yearly predicted yield with a 95% initial soil water level increased by 75 lbs./ac. With the 50% initial soil water level, there was a smaller yield increase of 30 lbs./ac. These results are for one irrigation strategy on one of a myriad of soil types that might be encountered in an actual field. Other examples might show different amounts of change in yield or no change in yield at all. Use of the crop simulation allowed for an understanding of how each soil responded to different irrigation application rates.

Conclusions

Evaluation of the value of implementing site-specific irrigation on individual field will need performed on a field-by-field basis. As illustrated here, crop models such as GOSSYM can serve as tools to aid in this evaluation. The yield response characteristics of the soils in a field can be assessed to determine which direction to increase or decrease irrigation for each soil. In the case illustrated average yearly yield increased when management was changed from a uniform applications to site-specific applications. Increases in yield would create more revenue for a farmer, thus allowing for a site-specific system to pay for itself. The yield increases were not consistent in every year, though. Some years had yield gains in the site-specific case, while some had no gains. Inconsistent yield increases with site-specific systems mean that a farmer would need to consider multiple years when budgeting for the expense of such a system.

Thanks go to Jim Bordovsky, Frank Mazac, and Dana Porter of Texas A&M University for taking time from their busy schedules to answer questions about management parameters and assist with data acquisition.

References

Baker, D. N., J. R. Lambert, and J. M. McKinion. 1983. GOSSYM: A simulator of cotton crop growth and yield. South Carolina Agricultural Experiment Station Bulletin 1089 Clemson University, Clemson, South Carolina.

Camp, C. R., E. J. Sadler, D. E. Evans, L. J. Usrey, and M. Omary. 1998. Modified center pivot system for precision management of water and nutrients. Applied Engineering in Agriculture 14(1):23-31.

Evans, R. G., S. Han, M. W. Kroeger, and S. M. Schneider. 1996. Precision center pivot irrigation for efficient use of water and nitrogen. In Precision Agriculture. ASA-CSSA-SSSA

Paz, J. O., W. D. Batchelor, T. S. Colvin, S. D. Logsdon, T. C. Kaspar, D. L. Karlen. 1998. Analysis of water stress effects causing spatial yield variability in soybeans. Transactions of the ASAE. 41(5):1527-1534.

Perry, C., S. Pocknee, O. Hansen, C. Kvien, G. Vellidis, and E. Hart. 2002. Development and testing of a variable-rate pivot irrigation control system. ASAE Technical Paper No. 022290. ASAE. St. Joseph, MI.

Reddy, K. R., V. G. Kakani, J. M. McKinion, and D. N. Baker. 2002. Applications of a cotton simulation model, GOSSYM, for crop management, economic, and policy decisions. In Agricultural System Models in Field Research and Technology Transfer. Eds. L. R. Ahuja, L. Ma, and T. A. Howell. Lewis Publishers. Washington, D.C.

South Plains Evapotranspiration Network. n.d. South Plains Evapotranspiration Network climate data. Retrieved December 19, 2002 from http://lubbock.tamu.edu/irrigate/et/etMain.html. Lubbock, Texas.

Texas Agricultural Extension Service. n.d. County estimates. Retrieved October 15, 2002 from http://www.nass.usda.gov/tx/. Austin, Texas.

United States Department of Agriculture, Soil Conservation Service. 1979. Soil survey of Lubbock County, Texas

Table 1. Irrigation Application Dates.

May 15	July 14
June 2	July 21
June 9	July 28
June 16	August 4
June 23	August 11
June 30	August 18
July 7	August 25

Table 2. GOSSYM input parameters.

Planting Date:	May 1
Emergence Date:	May 7
Simulation End Date:	October 15
Variety:	Mid
Row Spacing	40 inches
Plants per foot	2.98

Table 3. 1.5 inch application rate results.

				Olton Soil		Amarillo Soil	
Year	Rainfall (in.)	Seasonal Irrigation (in.)	Total Water (in.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)
2001	7.20	16.00	23.20	1710	1625	1655	1585
2000	8.50	17.44	25.94	1495	1485	1275	1300
1999	16.56	17.47	34.03	1280	1280	1300	1300
1998	5.55	18.63	24.18	1785	1785	1780	1685
1997	11.61	18.63	30.24	1220	1215	1190	1185
1995	15.08	14.17	29.25	1055	1055	1030	1020
				1367	1364	1315	1298

Table 4. 1.0 inch application rate results.

				Olton Soil		Amarillo Soil	
Year	Rainfall (in.)	Seasonal Irrigation (in.)	Total Water (in.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)
2001	7.20	11.00	18.20	1710	1625	1120	270
2000	8.50	12.44	20.94	1495	1490	1215	1100
1999	16.56	12.50	29.06	1285	1280	1290	1255
1998	5.55	12.79	18.34	1845	1690	1615	485
1997	11.61	12.79	24.41	1195	1195	1145	985
1995	15.08	10.57	25.65	1050	1020	855	495
				1374	1335	1224	864

Table 5. 0.50 inch application rate results.

				Olton Soil		Amarillo Soil	
Year	Rainfall (in.)	Seasonal Irrigation (in.)	Total Water (in.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)	95% Full Initial Profile Yield (lbs./ac.)	50% Full Initial Profile Yield (lbs./ac.)
2001	7.20	5.50	12.70	1605	1545	195	150
2000	8.50	6.50	15.00	1475	1415	675	345
1999	16.56	6.50	23.06	1325	1320	675	325
1998	5.55	6.50	12.05	1705	1645	235	290
1997	11.61	6.50	18.11	1190	1180	640	225
1995	15.08	6.34	21.42	1030	980	165	275
				1345	1308	478	292

Table 6. 0.60 inch application rate results.

Year	Rainfall (in.)	Seasonal Irrigation (in.)	Total Water (in.)	Olton Soil 95% Full Initial Profile Yield (lbs./ac.)	Olton Soil 50% Full Initial Profile Yield (lbs./ac.)	Amarillo Soil 95% Full Initial Profile Yield (lbs./ac.)	Amarillo Soil 50% Full Initial Profile Yield (lbs./ac.)
2001	7.20	6.60	13.80	1615	1555	205	150
2000	8.50	7.80	16.30	1480	1475	830	480
1999	16.56	7.80	24.36	1325	1325	940	565
1998	5.55	7.80	13.35	1690	1685	315	305
1997	11.61	7.20	18.81	1190	1180	975	235
1995	15.08	7.44	22.52	1035	995	260	270
				1344	1332	664	371

Table 7. 0.40 inch application rate results.

Year	Rainfall (in.)	Seasonal Irrigation (in.)	Total Water (in.)	Olton Soil 95% Full Initial Profile Yield (lbs./ac.)	Olton Soil 50% Full Initial Profile Yield (lbs./ac.)	Amarillo Soil 95% Full Initial Profile Yield (lbs./ac.)	Amarillo Soil 50% Full Initial Profile Yield (lbs./ac.)
2001	7.20	4.40	11.60	1600	1540	185	140
2000	8.50	5.20	13.70	1470	1400	580	225
1999	16.56	5.20	21.76	1320	1320	535	295
1998	5.55	5.20	10.75	1690	1635	195	235
1997	11.61	4.80	16.41	1190	1175	295	200
1995	15.08	5.24	5.24	1030	980	140	250
				1340	1302	349	241

Table 8. Total field yield comparison between uniform and variable rate irrigations – 95% initial soil water content.

Year	Uniform 0.5” AR (lbs./ac.)	0.4” Olton AR with 0.6” Amarillo AR (lbs./ac.)
2001	900	903
2000	1075	1150
1999	1000	1130
1998	970	1003
1997	915	1083
1995	598	645
Average:	910	985

Table 9. Total field yield comparison between uniform and variable rate irrigations – 50% initial soil water content.

Year	Uniform 0.5" AR (lbs./ac.)	0.4" Olton AR with 0.6" Amarillo AR (lbs./ac.)
2001	848	845
2000	880	940
1999	823	943
1998	968	970
1997	703	705
1995	628	625
Average:	808	838

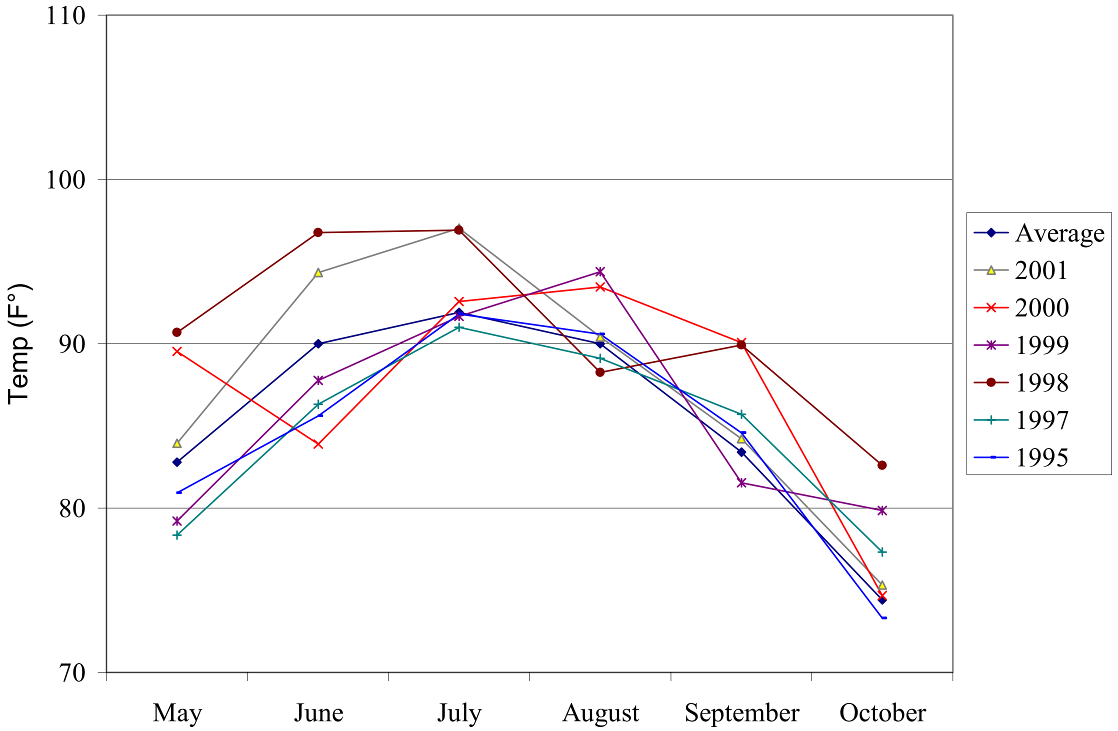

Figure 1. Average monthly high temperature for simulation years.

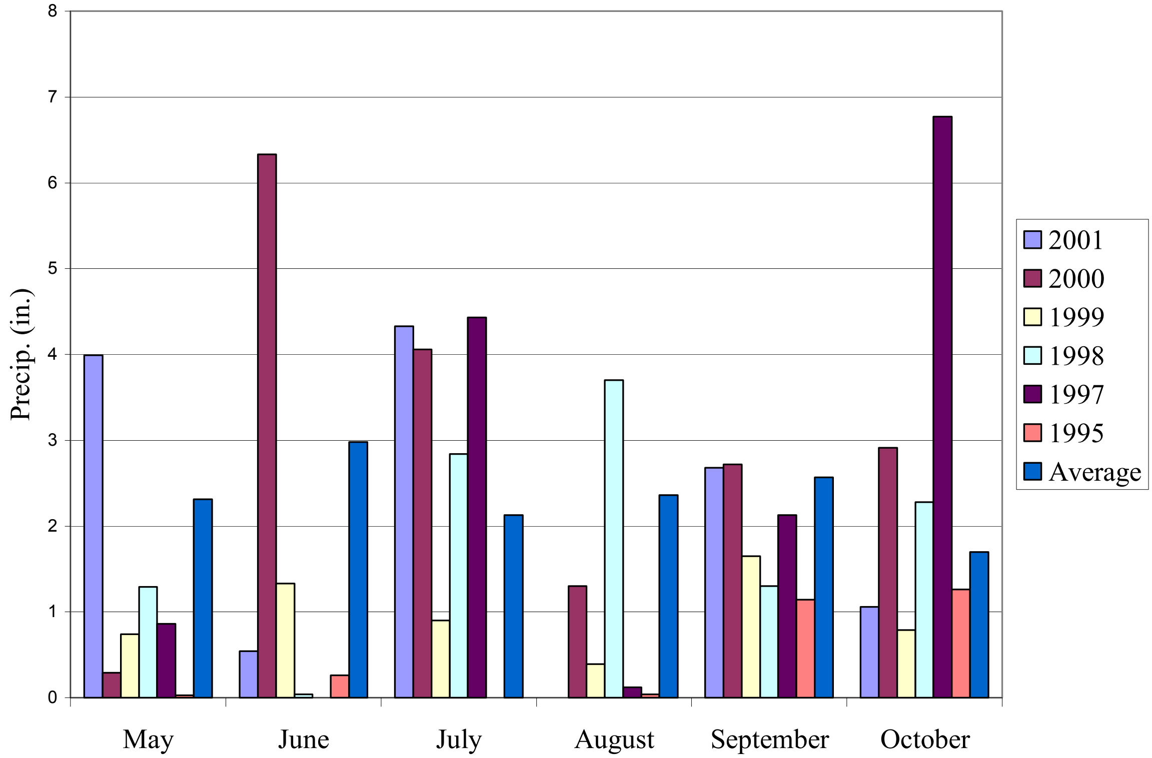

Figure 2. Average monthly precipitation for simulation years.

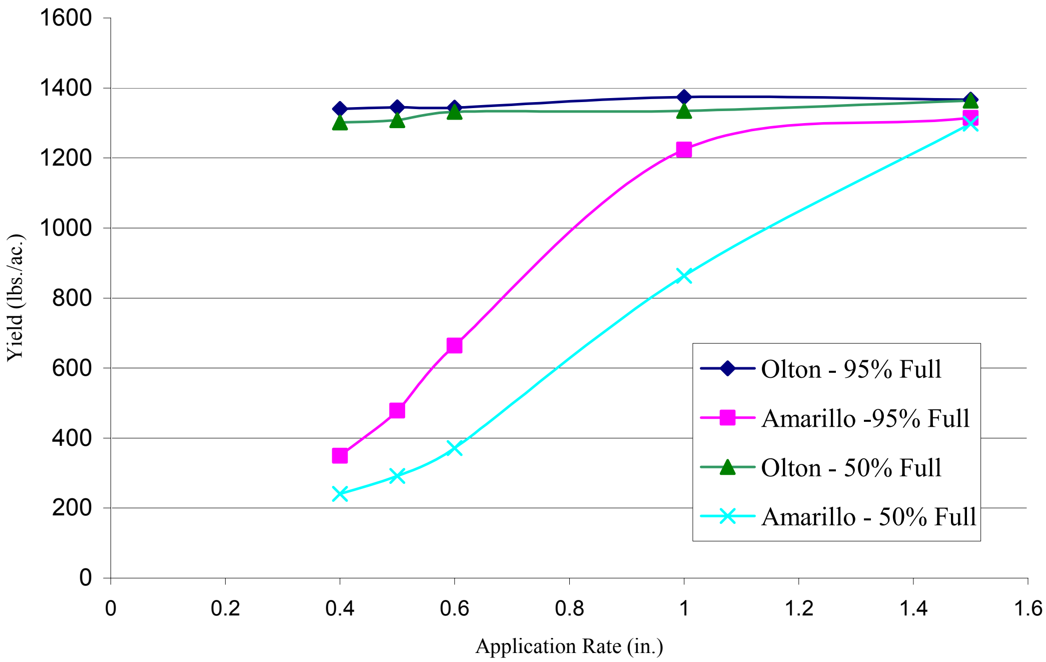

Figure 3. Cotton yield response by soil for five irrigation application rates and two levels of beginning profile soil water levels.