Paper Number: 032138
An ASAE Meeting Presentation
This is not a peer-reviewed article.

Various Irrigation Effect of Corn Grain Yield and CERES-Maize Simulation for South Central Kansas

E. Dogan, PhD
Kansas State University, Biological & Ag Engineering
147 Seaton Hall, Manhattan, KS 66506

Gary A. Clark
Professer, Biological & Ag Engineering
Kansas State University, 147 Seaton Hall, Manhattan, KS 66506

Danny H. Rogers
Professor, Extension Engineer, Irrigation, Biological & Ag Engineering, Kansas State University, 237 Seaton Hall, Manhattan, KS 66506

Richard L. Vanderlip
Professor, Agronomy, Kansas State University, 3724 Throckmorton Hall, Manhattan, KS 66506

Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel & Convention Center
Las Vegas, Nevada
July 27-July 30, 2003

Abstract. *A field study was conducted to evaluate an irrigation scheduling model (KanSched) under deficit sprinkler irrigation applications on seven irrigated corn sites in South Central Kansas from 1999 to 2001. The study sites included a K-State experimental field with a linear move irrigation system and six commercial production fields with center pivot sprinkler systems. The sprinkler packages were modified to apply various irrigation amounts on three portions of the systems. Soil types from the various fields ranged from coarse textured sand to fine textured silt loam. Net irrigation amounts applied to each test zone were measured with three IrriGages (IG10). One IG10 collector was also located at the edge of each commercial site to measure rainfall during the corn growing season. Field yield and water use information was collected. Field results were compared to modeled yields using the CERES-Maize crop model. Field information generally indicated substantial yield loss due to deficit irrigation. CERES-Maize simulations did not mimic measured yields*

Keywords. Deficit irrigation, crop model, scheduling

Various Irrigation Effect of Corn Grain Yield and CERES–Maize Simulation for South Central Kansas

E. Dogan, G.A. Clark, D.H. Rogers, R. L. Vanderlip[1]

ABSTRACT

A field study was conducted to evaluate an irrigation scheduling model (KanSched) under deficit sprinkler irrigation applications on seven irrigated corn sites in South Central Kansas from 1999 to 2001. The study sites included a K-State experimental field with a linear move irrigation system and six commercial production fields with center pivot sprinkler systems. The sprinkler packages were modified to apply various irrigation amounts on three portions of the systems. Soil types from the various fields ranged from coarse textured sand to fine textured silt loam. Net irrigation amounts applied to each test zone were measured with three IrriGages (IG10). One IG10 collector was also located at the edge of each commercial site to measure rainfall during the corn growing season. Field yield and water use information was collected. Field results were compared to modeled yields using the CERES-Maize crop model. Field information generally indicated substantial yield loss due to deficit irrigation. CERES-Maize simulations did not mimic measured yields.

INTRODUCTION

Deficit Irrigation

Martin et al. (1985) defined deficit irrigation as "the intentional under irrigation of crops with the objective of either water conservation or increased profitability over the long-term". Stegman (1986) pointed out that rising energy costs, along with aquifer depletion, encourage water users to consider deficit irrigation, which can help to prolong use of ground water in Great Plains. He studied the effect of reduced irrigation on corn yield in a subhumid climate near Oakes and Carrington, ND, in 1981 through 1983 using a sprinkler irrigation system. That study concluded that corn yield was reduced by 5% under reduced irrigation (about 25% less than full irrigation).

In general, deficit irrigated corn results in reduced yield (Stewart et al., 1975; Musick and Dusek, 1980; Lamm et al., 1994). Eck (1986) reported that yield was reduced when water stress was imposed on the corn plants and suggested that deficit irrigation on corn is not feasible in the southern High Plains. Lamm et al. (1993) studied the effect of deficit irrigation on corn grain yield and found that corn yield might be reduced by 0.14 Mg/ha for every one cm reduction in irrigation water below crop need and suggested that instead of deficit irrigation, reducing planting area might be a better option to the corn growers. Similarly, Lamm et al. (2001) studied the effect of nitrogen and irrigation rate on corn grain yield with subsurface drip irrigation. Irrigation rates of 75, 100, and 125% and reported similar results. Musick and Dusek (1980) reported similar results using surface (basin) irrigation in Bushland, TX in 1975 through 1977.

[1] E. Dogan, Recent PhD Graduate, Kansas State University, Dept. of Biological & Ag Engineering; G.A. Glark, Professor, Department of Biological & Ag Engineering, Kansas State University; D. H. Rogers, Professor and Extension Agricultural Engineer, K-State Research and Extension, and R.L. Vanderlip, Professor, Agronomy, Kansas State University.

However, Gilley and Mielke (1980) conducted a study in Nebraska where 90% of crop water need was supplied during the reproductive stage and 80 % during the grain filling stage of corn and concluded that corn grain yield was not substantially reduced.

CERES-Maize Crop Model

Limited water resources and increasing pumping energy cost may cause farmers to consider deficit irrigation as an alternative to full irrigation practices. Unfortunately, existing literature indicates potential yield losses with deficit irrigation practices. Alternatively, farmers may try to either reduce planted area or schedule irrigation events so that plants do not stress during sensitive growth stages. CERES-Maize may provide valuable information to irrigators about their crops development and yield and help them to assess the gains and losses of a deficit irrigation schedule. Farmers can even decide if it is economical to deficit irrigate their crop with the expected environmental conditions and determine their farming strategies.

CERES-Maize (Crop-Environment Resource Synthesis) (Jones and Kiniry, 1986) is designed to mimic corn grain response in a given year and location (Garrison et al., 1999). CERES-Maize yield response has been tested in Virginia (Hodges et al., 1987), Illinois (Kunkel et al., 1994), and Australia (Hargreaves and McCown, 1988). Llewelyn and Featherstone (1997) indicated that the CERES-Maize model is an important model and has been widely used to assess irrigation strategies for corn. Kiniry and Brockholt (1998) conducted a study in 9 locations in Texas with variable weather conditions and soil types to evaluate CERES-Maize grain response to measured ones. Mean simulated corn grain yield from all sites in 5 years were within 10% of measured corn grain yield except at one location and that was within 13%. They considered those results promising enough for CERES-Maize to be used for corn grain yield simulations.

Kiniry et al. (1997) evaluated the yield response of two maize models (ALMANAC and CERES-Maize) for nine locations in Minnesota, New York, Iowa, Illinois, Nebraska, Kansas, Missouri, Louisiana, and Texas. In that study, they used one major corn-producing county in each state and compared simulated yield results with dryland yields. They found that both ALMANAC and CERES-Maize satisfactorily simulated mean grain yield within 5% of measured grain yields for all nine locations. Hodges et al. (1987) evaluated the CERES-Maize grain yield estimations in 14 states accounting for 85% of US corn production in 1982 through 1985 using information from 51 weather stations. CERES-Maize simulations in 1982 were used to calibrate the model. CERES-Maize simulation results showed that yield estimates were 92, 97, 98, and 101% of US government projected corn grain yields for all 14 states. Those results showed that the model might be used for large area corn grain yield estimations with minimal regional calibrations.

MATERIALS AND METHODS

Experimental Design

A field study was conducted from 1999 through 2001 to evaluate the effect of deficit sprinkler irrigation amounts on corn grain yield in South Central Kansas. The research was conducted on one experimental field (KSU Sandyland Experimental Field, SL) and 6 commercial corn production sites (GH, PS, JM, GS, SM, and TZ). All commercial field sites had center pivot

(CP) sprinkler systems while the SL site had a linear-move irrigation system. Because greater system control was available at the SL site, irrigation rates of 65, 100, and 135% (treatments I, II, and III) were used. The 100% rate at the SL site was scheduled using the KanSched program. (KanSched is an ET-based irrigation scheduling program further described by Clark et.al. 2002a). Because the commercial corn production sites were typically irrigated on “the wet side”, the sprinkler nozzle sizes on three spans of each sprinkler irrigation system were modified to apply about 50, 75, and 100% of full irrigation (treatments I, II, and III). On some systems, the treatment III span required no adjustment, while on the other systems pressure regulators and nozzle sizes were added and modified to obtain the desired rate.

Sixteen sprinkler drops on three of the four spans of the SL linear-move system were modified with the designed nozzle pressure combinations (Table 1). Treatment zones were located in the middle of each span. On commercial field sites, three CP spans were modified with designed nozzle and pressure combinations that were assigned to the middle 5 sprinkler drops to insure adequate irrigation overlap. Sprinkler irrigation drops on all systems were 2.0 to 2.4 m from the soil surface. Most of the irrigation systems had 172 kPa pressure regulators but a few had 103 kPa pressure regulators (Table 1). All of the CP spans used in this study were close to the pivot point to minimize the impact of the modification on total production. This was an important consideration to the cooperators. The JM site involved two identical systems on adjacent fields. The site used in 2000 had a limited water allocation that did not allow full irrigation for the season. However, in 2001, the study was moved to an adjacent field that had a similar CP system, but with a water right that allowed full irrigation. Because of site manager concerns on the SM site in 2000, treatments I and II were adjusted to apply 70% and 85% of full irrigation.

Table 1. Sprinkler irrigation system and nozzle characteristics used in 1999, 2000, and 2001.

Site	Nozzle Spacing (m)	Nozzle Pressure (kPa)	Flow Rate[1] (L/s)			Distance to pivot point (m)		
			I	II	III	I	II	III
SL	3.0	103	0.30	0.43	0.60	-----	-----	-----
GH	4.8	172	0.14	0.34	0.31*	92	154	116
PS	5.6	172	0.20	0.22	0.49	60	88	194
JM	2.9	103	0.12	0.13	0.28	94	112	273
GS	5.2	172	0.21*	0.40*	0.47*	76	102	128
SM	5.5/4.9	172	0.21	0.43	0.54*	86	126	155
TZ	5.6	172	0.20*	0.21*	0.48*	60	88	116

[1]Discharge rates with * are manufacturer reported values the others are measured.

The soils on the sites ranged from fine sandy loams to a silty clay and are shown in Table 2.

Table 2. Soil physical properties of all commercial and experimental sites used in 1999, 2000, and 2001.

Sites	Soil Class	Depth from surface (cm)	USDA texture	Permeability (mm/d)	Available water capacity (cm/cm)	Location (County)
SL	Pratt-Tivoli associations	0.0-17.8 17.8-35.6 35.6-81.3	Fine sandy loam	15.3-50.8 5.1-50.8 1.5-5.1	0.11-0.20 0.12-0.20 0.12-0.20	Stafford
GH	Pratt-Carwile associations	0.0-36 36-127	Fine sandy loam Light sandy clay loam	12.7-25.4 5.0-12.7	0.15 0.17	Reno
PS	Bethany-Tabler associations	0.0-41 41-114	Silt loam Silty clay loam	5.1-12.7 5.1-12.7	0.18 0.17	McPherson
JM	Blanket-Farnum associations	0.0-56 56-152	Loam	15.2-50.8 50.8-15.2	0.20-0.22 0.14-0.21	Stafford
GS	Crete-Ladysmith associations	0.0-27.9 27.9-43.2 43.2-116.8	Silt loam Silty clay loam Silty clay	16.0-5.1 5.1-16.0 1.5-5.1	0.14-0.18 0.15-0.19 0.14-0.18	Harvey
SM	Pratt-Carwile associations	NA	Loamy fine sand	50.8-127.0	0.12	Pratt
TZ	Naron-Pratt-Carwile associations	0.0-35.6 35.6-101.6	Fine sandy loam Sandy clay loam	16.0-50.8 16.0-50.8	0.09-0.13 0.12-0.16	Rice

Data Collection

In 1999 through 2001, site managers (farmers or crop consultants) scheduled irrigation events on the commercial sites based on treatment III (full irrigation). However, at the SL site, irrigation events on treatment II (full irrigation) were scheduled using KanSched. Irrigation amounts within each test zone on all sites were measured with 3 IrriGages (IG10) (Clark et al., 2002b) at a 62 cm height. One IG10 collector was also located outside of the irrigated area of all commercial sites to measure rainfall amounts. Sites were visited once or twice each week during the corn growing season to read irrigation depths and rainfall amounts. Those data were later used to create a field soil water balance (SWB) of each site and for use as inputs for CERES-Maize simulations.

Weather data used in KanSched and CERES-Maize simulations were obtained from automated weather stations close to each site. Weather data included daily grass reference evapotranspiration (ETo), maximum and minimum daily temperatures (°C), and solar radiation (MJ/m^2). Rainfall and ETo data were used in the KanSched simulations and maximum and minimum daily temperatures, solar radiation and rainfall were used in CERES-Maize simulations.

Field Water Balance Simulations

A field water balance was simulated using the KanSched program. That program uses soil water holding capacity, permanent wilting point, emergence date, crop root depth, crop canopy coverage at different growth stages, and end of the growth stage as inputs. To calculate available soil water, KanSched maintains a field water budget with daily inputs of ETo, rainfall, and irrigation amounts. The KanSched program uses only one soil texture for the management root depth. Therefore, soil water calculation in the program is for the entire defined active crop root depth. Most of the active roots for all field sites were observed to be within the top 60 cm of soil and therefore the KanSched active root depth was set to 60 cm. However, while some crop roots were deeper and had access to that water, they were not considered in the main water balance.

Crop coefficients (kc), used to calculate daily crop water requirements (KanSched-based crop evapotranspiration, ET_{ks}) were generated by KanSched and obtained from the USDA Soil Conservation Service/National Engineering Handbook (USDA, 1993). A basal crop coefficient (kc) was created using kc values of 0.25, 1.20, and 0.60 for the beginning, peak growth, and maturation stages of the corn crop, respectively. The KanSched program also adjusts (reduces) crop coefficients when the calculated soil water content is less than the management allowed deficit (MAD) level (50%) according to procedures outlined in chapter 2 of the National Engineering Handbook (USDA, 1993).
The KanSched program was run for all treatments and years to determine soil water balance parameters associated with the effects of deficit irrigation. Additionally, the program was run to determine non-stressed crop evapotranspiration (ET_{ks}^*). At the beginning of all runs, the initial soil water status of the soil profile was assumed to be at field capacity. KanSched also charts effective irrigation, precipitation, and soil water changes.

Corn Harvest

In all three years, 6.1 m long sections of three corn rows from all sites and treatment zones were hand harvested at physiological maturity. Corn ears were later sun dried and then shelled and weighed Measured corn yields were corrected to 15.5% moisture content. Since each harvested corn row was not a true replication but rather a sub-sample, yield data were analyzed graphically.

CERES-Maize Simulations

The CERES-Maize model was run with field data collected from 1999 through 2001 that included site-based irrigation and rainfall amounts. Additionally, the CERES-Maize model was run to find the crop evapotranspiration (ET_{cm}^*) under no water stress conditions.

At the beginning of the CERES-Maize simulations, soil water status was set to field capacity as in KanSched simulations. Planting dates, corn hybrids, seeding rates, and irrigation event and rainfall dates for all sites and years were determined by consulting with the site managers and with measured site data.

Morphological and physiological coefficients for the corn hybrids used on all commercial sites were not available. Therefore, coefficients for Pioneer Seed Co. Hybrid 3162 were used for the commercial site simulations. That hybrid was widely (60 to 70%) used by the farmers in the area. This hybrid has a 119-day maturity, which is common for the area (Belz, 1998). For the SL simulations, actual hybrid (NC+5445) coefficients were used.

General inputs included planting date, plant population (seed/ha), row spacing (cm), planting depth (cm), and in-season irrigation amounts. Corn harvest occurred at grain maturity. Since collected irrigation depths were net amounts, sprinkler irrigation system efficiency in the CERES-Maize simulations was assumed to be 100%. The CERES-Maize model was run to simulate ET_{cm}, ET_{cm}^{*} and corn grain yields to determine if Ceres-Maize could mimic the measured yields for South Central Kansas. Because simulated yields were reported as dry matter, values were adjusted to 15.5% dry-basis moisture content.

RESULTS AND DISCUSSION

Measured and KanSched Simulation Results

In 1999, designed and measured treatment irrigation application rate percentages for all sites strongly agreed with less than 5% difference (Table 3). In 2000 and 2001, designed and measured values were also similar and were within 10% difference except on the PS site in 2001 (Table 3). Variations in system inline pressure, pressure regulator performance, nozzle discharge rates, and distribution losses of applied water were probable causes of differences.

In 1999 and 2000, measured net irrigation depths from all sites and treatments ranged from 71 to 406 mm and from 100 to 335 mm, respectively. In 2001, net irrigation amounts for all treatments were higher and ranged from 191 to 459 mm (Table 3). In 1999, half of the treatments were deficit irrigated (-) and ranged from 35 to 87 mm below net irrigation amounts from the non-stressed KanSched runs, where excess irrigation depths ranged from 8 to 139 mm above net irrigation requirements. In 2000, most of the irrigation amounts were deficit (10 to 141 mm). Only three treatment sites had excess irrigation that ranged from 6 to 68 mm. Similarly, in 2001, most of the treatment sites were deficit irrigated (20 to 180 mm) with two excess irrigation treatments (27 and 29 mm). In 1999, observations on all sites indicated no visual water stress on deficit irrigated corn plants. However, in 2000 and 2001, there was obvious visual water stress on the deficit irrigated corn plants during the middle and late periods of the corn growing season. In 1999 and 2000, ET_{ks} values ranged from 370 to 488 mm and from 356 to 498 mm, respectively. In the drier 2001 season, ET_{ks} values ranged from 386 to 566 mm. The 2001 season was hotter, had more solar radiation, and higher water demands than 1999 or 2000 seasons.

In 1999, measured corn grain yield ranged from 8.3 to 13.1 Mg/ha (Table 4). In that year, weather conditions were mild and treatment I imposed yield reductions on two sites (SL and TZ). In 2000 and 2001, corn yield ranged from 7.4 to 14.4 Mg/ha and from 3.8 to 16.1 Mg/ha, respectively. In those two years, rainfall was less (254 mm and 233 mm) than 1999 (355 mm) and deficit irrigation practices reduced corn yield.

Table 3. Treatment irrigation application rate percentages (design and measured) with measured net irrigation (Net Irrig.), excess or deficit irrigation amounts, and KanSched simulated crop ETc (ET_{ks}) values for all sites in 1999, 2000, and 2001.

Sites	Trt	Irrig. Applic. Rate (%)		Net Irrig. (mm)	Excess + or Deficit – Irrig. (mm)	ET_{ks} (mm)
		Design (%)	Measured (%)			
1999						
	I	65	66	165	-64	370
SL	II	100	100	250	+21	430
	III	135	138	344	+115	439
	I	41	44	71	-81	416
GS	II	74	73	117	-35	444
	III	100	100	160	+8	457
	I	54	54	219	-48	436
SM	II	74	73	297	+30	475
	III	100	100	406	+139	488
	I	56	55	142	-87	406
TZ	II	75	72	185	-44	423
	III	100	100	257	+28	445
2000						
	I	65	64	165	-114	369
SL	II	100	100	256	-23	474
	III	138	131	335	+56	498
	I	49	61	164	-115	371
GH	II	71	78	209	-70	391
	III	100	100	269	-10	393
	I	56	58	158	-45	421
PS	II	73	77	209	+6	426
	III	100	100	271	+68	426
	I	58	61	100	-141	356
JM	II	70	68	112	-129	362
	III	100	100	165	-76	392
	I	70	71	194	-111	357
SM	II	85	84	228	-77	379
	III	100	100	272	-33	385
TZ	I	56	67	201	-90	378
	II	75	83	164	-53	390
	III	100	100	243	-11	406

2001						
	I	49	60	247	-134	416
GH	II	71	77	315	-66	477
	III	100	100	410	+29	546
	I	56	82	191	-63	389
PS	II	73	85	197	-57	405
	III	100	100	233	-21	414
	I	58	55	252	-180	406
JM	II	70	73	333	-99	471
	III	100	100	459	+27	566
	I	70	70	244	-124	386
SM	II	85	87	304	-64	429
	III	100	100	348	-20	459

Table 4. Average corn grain yield for all sites in 1999, 2000, and 2001.

Site	Yield (Mg/ha)		
	I	II	III
1999			
SL	12.0	13.1	12.5
GS	10.6	9.5	10.7
SM	11.5	11.0	10.7
TZ	8.3	9.1	10.1
2000			
SL	7.4	11.0	10.9
GH	12.0	14.4	14.1
PS	12.7	11.0	12.1
JM	9.3	10.6	12.3
SM	8.8	11.5	11.6
TZ	9.7	11.9	12.5
2001			
GH	5.3	16.1	13.2
PS	13.4	15.6	14.1
JM	4.3	13.2	12.3
SM	3.8	8.8	12.6

Measured grain yield (Mg/ha) was more variable at lower ET_{ks} values (350 to 430 mm) than at higher ET_{ks} values (> 430mm) (Figure 1). Furthermore, with such variability the linear relationship (R^2 = 0.05) between those two parameters was weak. Figure 1 also indicates that there was no substantial yield increase for ET_{ks} values greater than 500 mm and that with lower water inputs high yields might be possible. However, lower ET_{ks} values indicated that some of the KanSched outputs such as effective irrigation and rain, soil water depletion (SWD), and resulting seasonal crop water use might be lower than actual values.

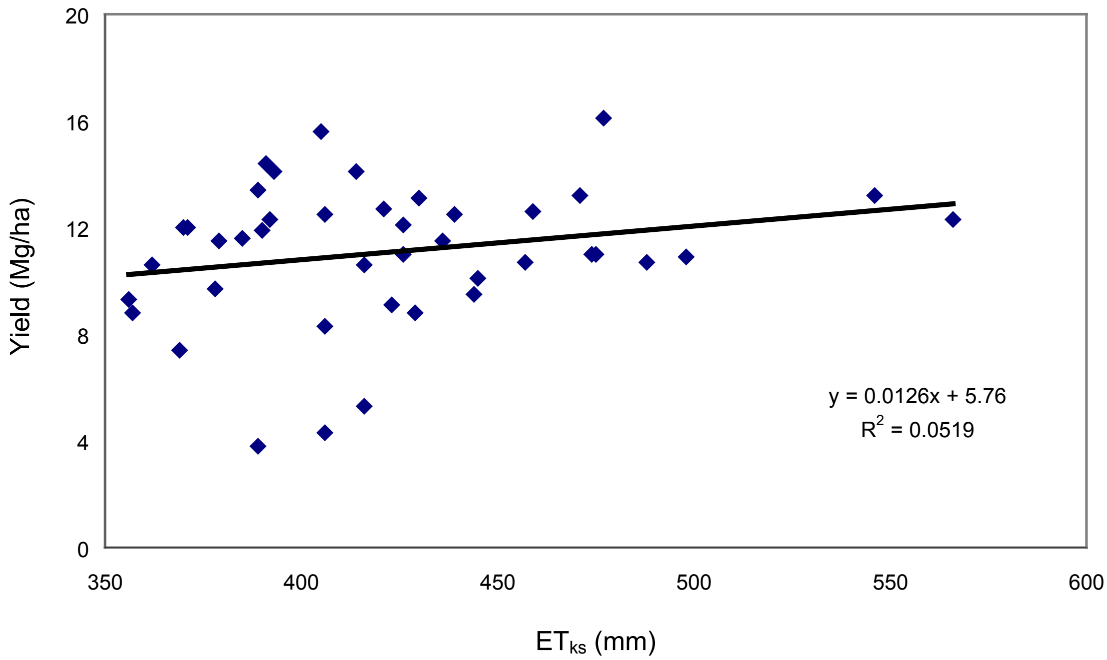

Figure 1. Measured yield and KanSched simulated corn evapotranspiration (ET_{ks}) for all sites, treatments, and years.

In Figure 2, measured grain yield is shown with the KanSched water balance ratio (R_w = Net irrigation + effective rain + soil water depletion / ET_{ks}^*) for all sites. The quadratic relationship between yield and the water balance ratio has an R^2 value of 0.25. The figure also indicates that the highest yield of the quadratic function is at a water balance ratio of 1.0, indicating that the KanSched irrigation scheduling program is accurate. Measured yields for R_w values of 0.85 and less, 0.85 to 1.0, and 1.0 or above were compared using a t-test analysis. Those results indicated that measured yields for R_w of 0.85 or lower were less ($p < 0.05$) than yields for R_w values of 0.85 to 1.0 or 1.0 and above. However, there was no yield difference between R_w values in the ranges of 0.85-1.0 and 1.0 or above. This again indicates that satisfactory yields can be obtained with KanSched-based irrigation schedules that maintain a relative water balance of 0.85 to 1.0. Any R_w value higher than 1.0 (full irrigation) will result in a use of water and energy with no yield benefit.

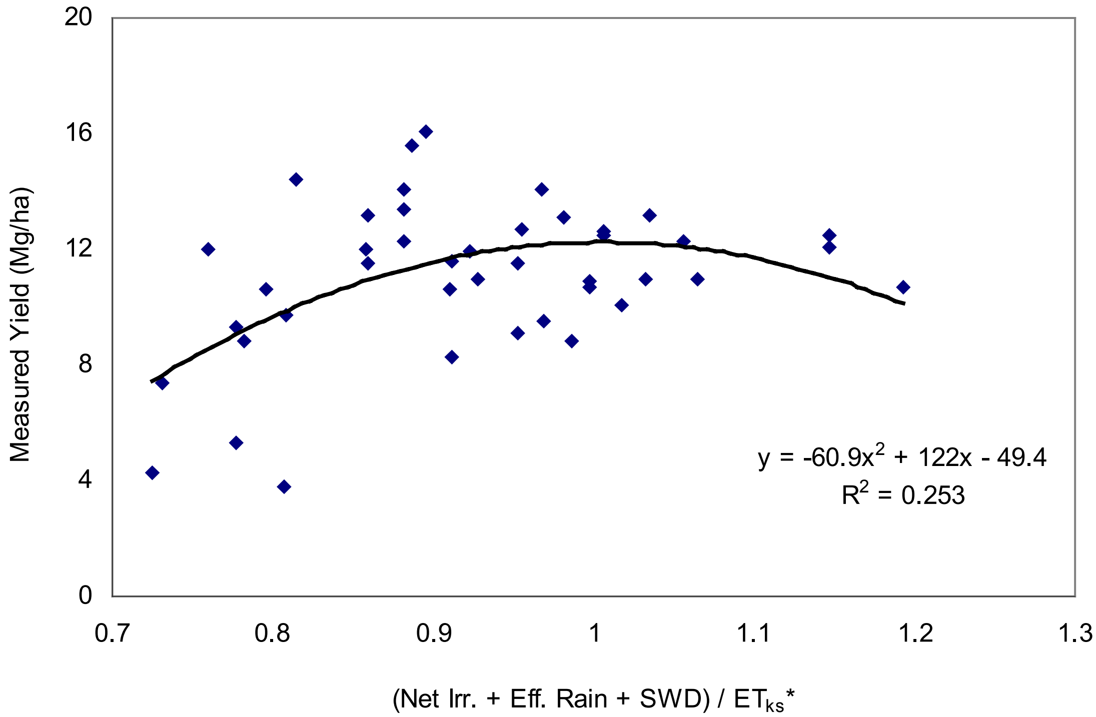

Figure 2. Measured yield with respect to the KanSched-based water balance ratio, R_w (Net Irr. + Eff. Rain + SWD / ET_{ks}^*) for all sites, treatments, and years.

Measured yield graphed with relative irrigation (R_I = Net applied irrigation amount / Net required irrigation amount) in Figure 3 has a quadratic relationship with an R^2 value of 0.18. The highest yield of the quadratic function occurs at an R_I value of 1.1. Even though the function indicates that reduced yield may occur with relative irrigation values less or more than 1.1, data indicate that farmers can manage their irrigation systems below R_I values of 1.0 (full irrigation) with potentially no yield loss. The highest yield reduction occurs at R_I values less than 0.7. Therefore, deficit irrigations with less than 70% of the full irrigation requirement will substantially reduce corn yield in that area. Figures 2 and 3 indicate that as long as the KanSched program soil water status is maintained at or above the MAD level (as shown in Figure 4) the highest corn yield might be expected.

Field site measured and KanSched calculated net irrigation amounts for the full irrigation treatments are plotted in Figure 5. For most commercial sites, full irrigation depths were within the targeted range except on two sites. One site was under irrigated (76 mm, JM, 2000), because of a limited water right. The other site (SM) over-irrigated (139 mm, 1999) in the wetter year of the study. The field scheduled treatment results (solid dots)from the SL site were very close to required amounts. Most of the commercial farm sites had applied net irrigation amounts that were very close to required values.

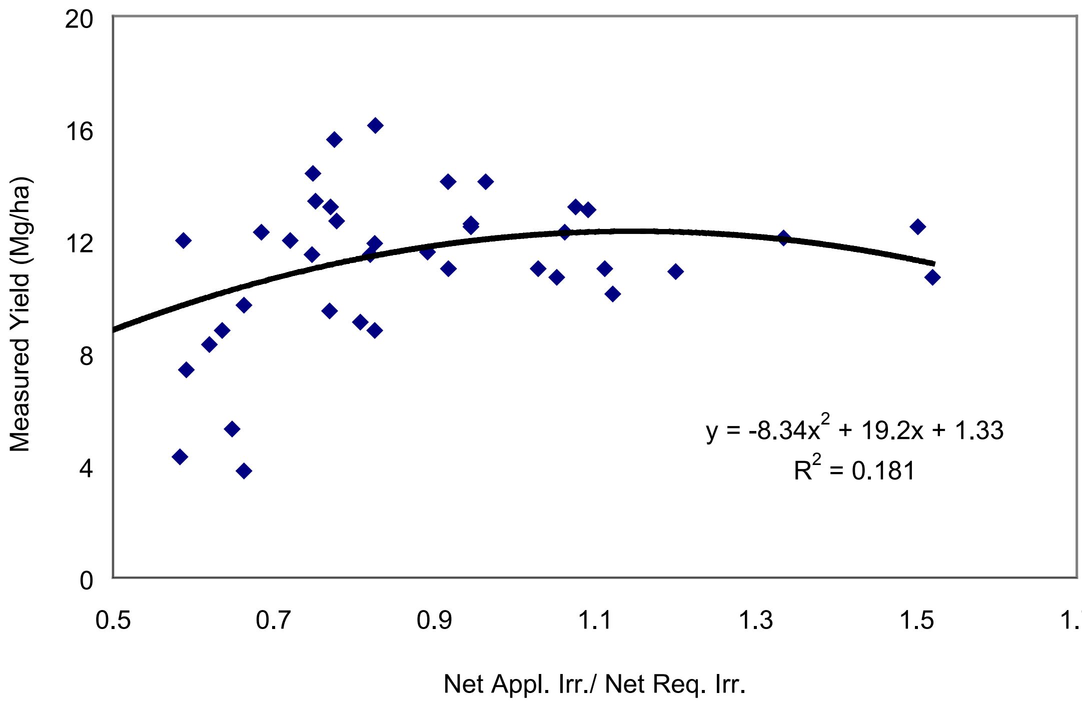

Figure 3. Measured yield and relative net irrigation (R_I = Net Appl. Irr. / Net Req. Irr.) from all sites (SL and commercial) and treatments in 1999, 2000, and 2001.

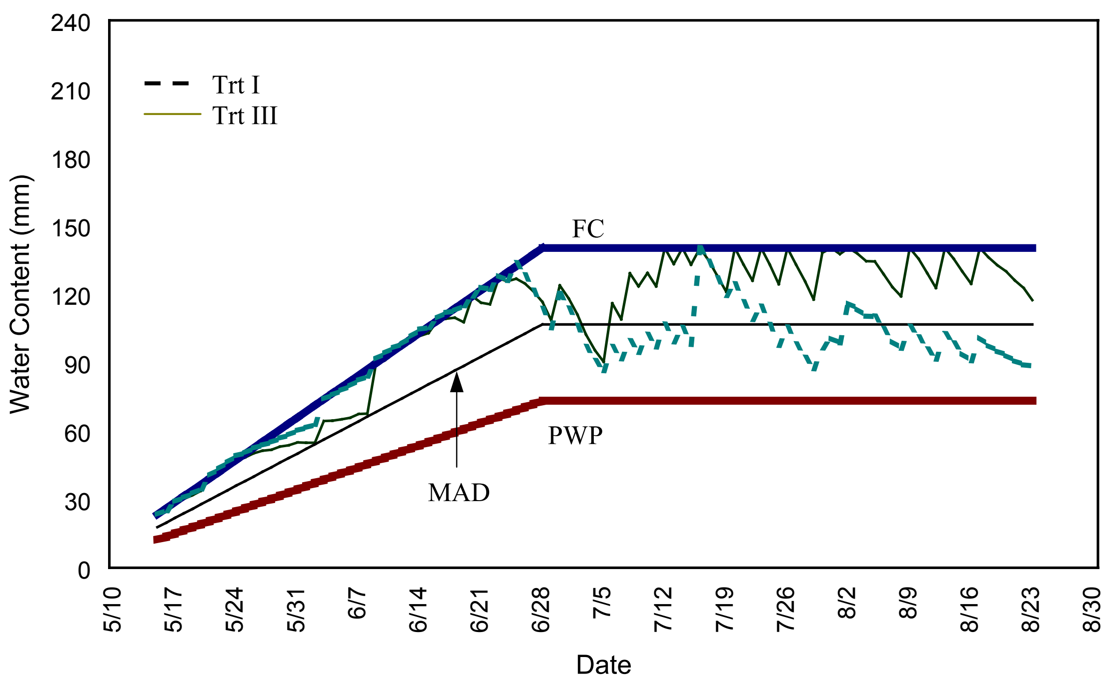

Figure 4. KanSched soil water budget for treatments I and III for site SM in 2001. The upper and lower heavy solid lines represent field capacity (FC) and permanent wilting point (PWP), respectively. The middle thin line represents the management allowed deficit (MAD) line (also known as the irrigation threshold).

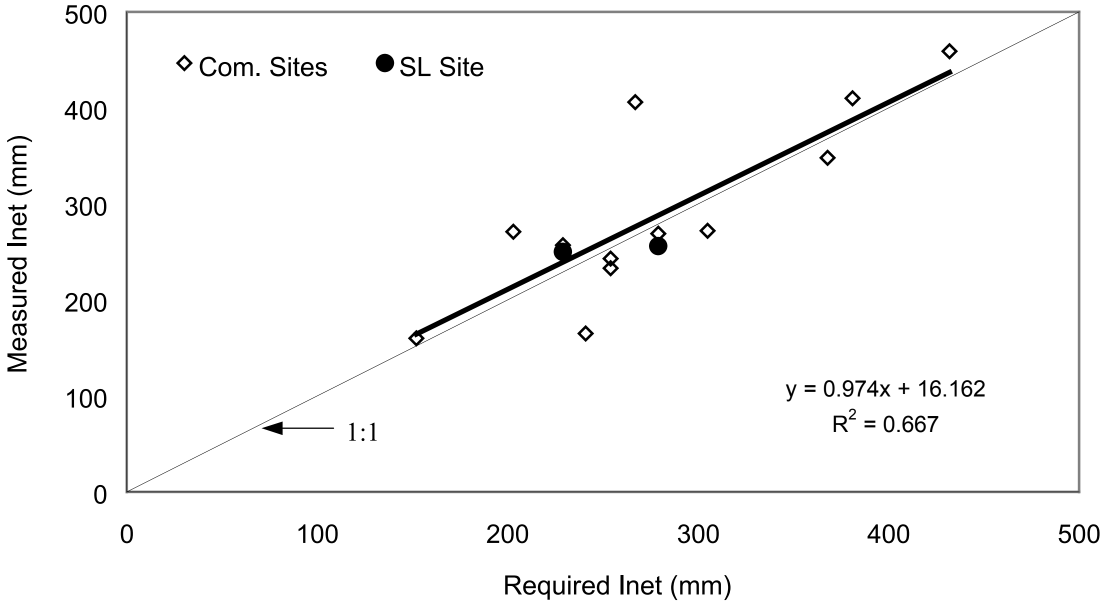

Figure 5. Measured net applied irrigation amounts for treatment III from commercial sites (Com.) and treatment II from the SL site and KanSched-based net required irrigation amounts for the same treatments and sites.

CERES-Maize Simulation Results

In 1999, 2000 and 2001, CERES-Maize simulated crop ET (ET_{cm}) ranged from 418 to 585 mm, 398 to 699 mm, and 409 to 712 mm, respectively. Simulated corn grain yield, from all treatments and sites ranged from 7.9 to 13.8 Mg/ha, 6.9 to 17.1 Mg/ha, and 6.6 to 13.8 Mg/ha in 1999, 2000, and 2001, respectively (Table 5). Simulated yields graphed with ET_{cm} values (Figure 6) increase linearly with crop ET ($R^2 = 0.44$). As might be expected, the simulated relationship was stronger than the relationship with measured data (Figure 1). The KanSched ET_{ks} values were consistently lower than CERES-Maize ET_{cm} values (Figure 7). Data were variable resulting in an R^2 value of 0.44. Probable reasons for the differences may include: (1) the KanSched crop ET values does not account for the first few weeks after planting which might be up to 25 - 30 mm; (2) the KanSched crop coefficients (kc) might be low; (3) ET_{ks} and ET_{cm} are each calculated using different ET models (Penman-Montieth and Priestly-Taylor, respectively); and (4) CERES-Maize calculates evaporation from wet surfaces, but the KanSched program does not. Simulated yields graphed with measured yields (Mg/ha) indicate a high variability and resulted in a low R^2 value of 0.16 (Figure 8). Simulated yields were typically higher than measured yields on the low end of the scale and were lower than measured yields on the higher end of the scale. Overall, Figure 8 indicates that CERES-Maize did not mimic measured yields for the south central Kansas conditions in this study.

Table 5. CERES-Maize simulated crop water use and yield for all sites in 1999, 2000, and 2001.

Site	ET_{cm} (mm)			Yield (Mg/ha)		
	I	II	III	I	II	III
1999						
SL	511	533	533	12.5	12.8	12.8
GS	585	585	585	13.8	13.8	13.8
SM	459	497	511	10.1	12.4	13.3
TZ	418	442	458	7.9	8.4	8.9
2000						
SL	537	618	699	9.7	12.5	17.1
GH	541	575	621	10.9	11.8	12.8
PS	541	541	541	14.0	14.0	14.0
JM	398	402	442	6.9	6.9	8.3
SM	434	446	486	9.2	9.9	11.0
TZ	416	443	466	11.4	13.2	13.4
2001						
GH	605	654	712	12.0	12.8	13.8
PS	526	561	567	9.9	10.0	10.8
JM	510	557	680	6.6	8.7	12.1
SM	409	470	497	7.2	9.6	10.1

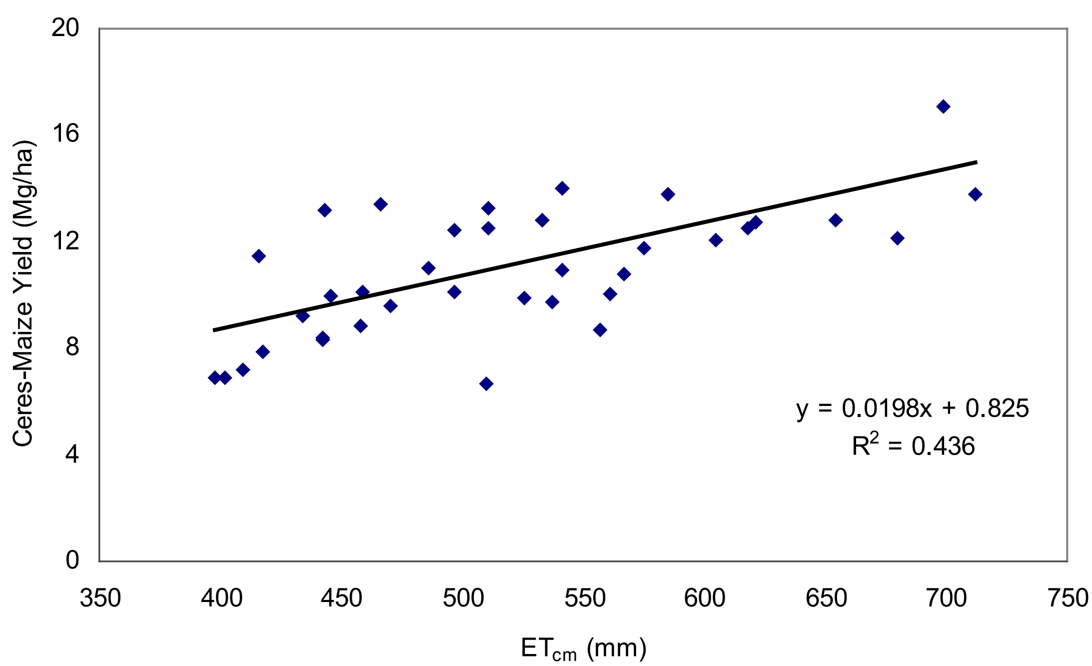

Figure 6. CERES-Maize simulated yield and CERES-Maize seasonal water use for all sites and treatments in 1999, 2000, and 2001.

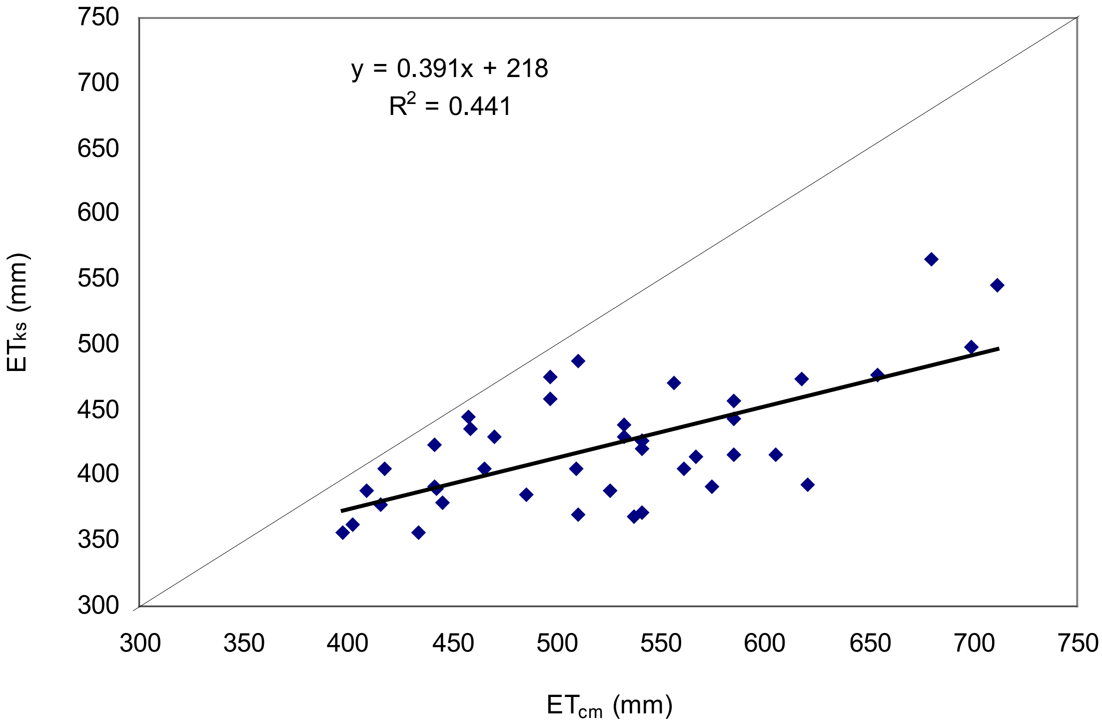

Figure 7. KanSched-based water use (ET_{ks}) versus CERES-Maize simulated crop water use (ET_{cm}) for all sites, treatments, and years.

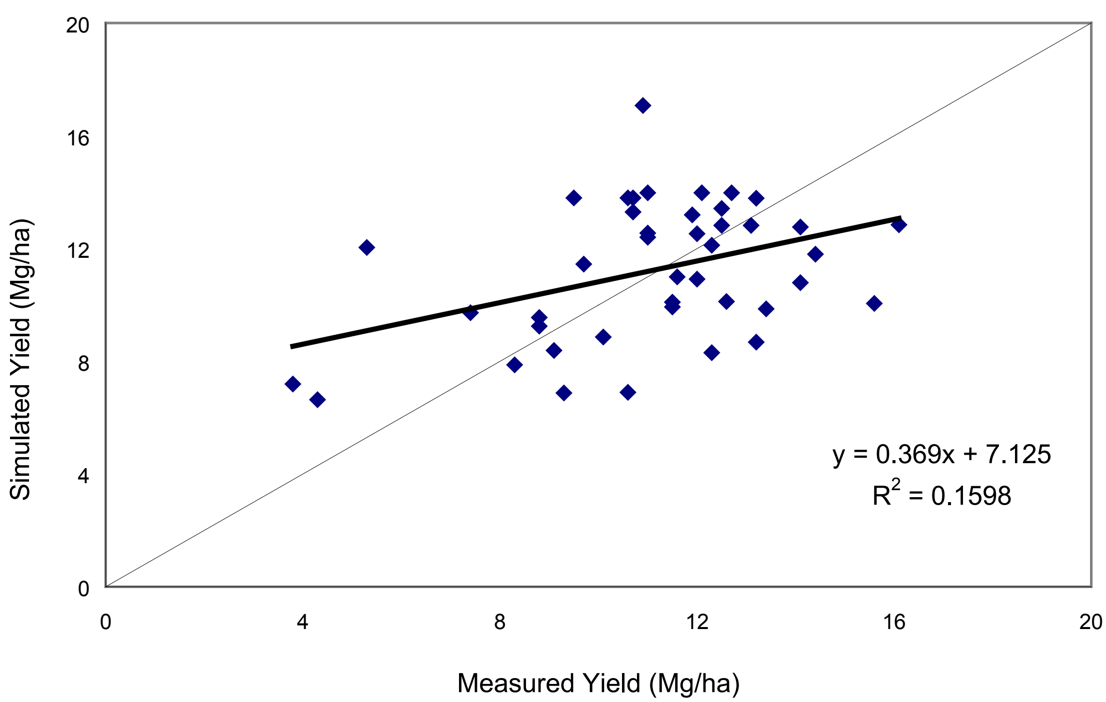

Figure 8. Simulated corn yield versus measured values for all sites, treatments, and years.

SUMMARY AND CONCLUSIONS

A field study was conducted to evaluate the effect of deficit sprinkler irrigation applications on corn grain yield in south central Kansas in 1999 through 2001. The research was conducted on 7 corn production sites (one experimental site and six commercial sites). Irrigation systems used in this study were one linear move sprinkler irrigation system on the experiment field site (SL) and center pivot (CP) systems on all commercial sites. The linear move system was nozzled to provide irrigation application rates of 65, 100, and 135% of full irrigation. The 100% rate irrigation treatment was scheduled using the KanSched program. The sprinkler packages on three spans of each CP system on the commercial sites were modified with selected nozzles to apply about 50, 75, and 100% of full irrigation amounts.

Corn growth simulation model (CERES-Maize v.3.5) yield response to deficit irrigation practices was also evaluated in this study. The CERES-Maize model was run with the data collected in 1999 through 2001 including irrigation, and precipitation amounts. Daily weather data used in the KanSched and CERES-Maize simulations were obtained from weather stations close to the sites.

Deficit irrigation amounts for all three years ranged from 10 to 180 mm while excess irrigation amounts ranged from 8 to 139 mm. Measured irrigation amounts for all sites and treatments ranged from 71 to 406 mm, 100 to 269 mm, and 191 to 559 mm in 1999, 2000, and 2001, respectively. The KanSched-based crop ET (ET_{ks}) ranged from 370 to 488 mm, 356 to 426 mm, and 386 to 566 mm while CERES-Maize simulated crop ET (ET_{cm}) ranged from 418 to 585 mm, 398 to 699 mm, and 409 to 712 mm for all sites in 1999, 2000, and 2001, respectively.

In 2000 and 2001, weather conditions were more demanding as compared to 1999. Therefore, deficit treatments affected yield more in those years than 1999. Corn grain yield from all treatments ranged from 9.5 to 13.1 Mg/ha, 7.4 to 14.4 Mg/ha, and 3.8 to 16.1 Mg/ha while CERES-Maize corn yield simulations for all treatment zones ranged from 7.9 to 13.8 Mg/ha, 6.9 to 17.1 Mg/ha, and 6.6 to 13.8 Mg/ha in 1999, 2000, and 2001, respectively.

The KanSched program results indicated that the soil water status was on target and that the highest yield with a quadratic function occurred at a relative water balance value of 1.0 (full irrigation). Furthermore, field data indicated that maintaining a water balance ratio between 0.85 and 1.00 resulted in no yield loss. Field water balance ratios that exceeded 1.0 did not have yield advantage. Overall, deficit irrigation, at water balance ratios of 85% or less, reduced measured yield especially in the drier years in south central Kansas. When CERES-Maize simulated yields were related to measured yields, no significant relationship existed ($R^2 = 0.16$). Results indicate that for farming purposes KanSched is a promising scheduling tool that can insure high corn yield in south central Kansas as long as the soil water status in the program is maintained between field capacity and the management allowed deficit.

REFERENCES

Belz, S. S. 1998. Simulation of reduced irrigation application effects on corn yield. M.S. thesis. Manhattan: Kansas State Univ.

Clark, G. A., D. H. Rogers, E. Dogan and R. Krueger. 2002a. The IrriGage: A non-evaporating in-field precipitation gage. ASAE paper no. 022068. St. Joseph, MI.10 p.

Clark, G., D. Rogers, M. Alam, D. Fjell, and S. Briggeman. 2002b. A mobile irrigation lab for water conservation: I. Physical and electronic tools. 2002 Conference Proceedings of the Irrigation Association. New Orleans, LA.

Eck, H. V. 1986. Effect of water deficits on yield, yield components, and water use efficiency of irrigated corn. Agron. J. 78: 1035-1040.

Garrison, M. V., W. D. Batchelor, R. S. Kanwar and J. T. Ritchie. 1999. Evaluation of CERES-Maize water and nitrogen balances under tile-drained conditions. Agricultural Systems 62: 189-200.

Gilley, J. R. and L. N. Mielke. 1980. Conserving energy with low-pressure center pivots. ASCE. J. Irrig. and Drainage Div. 106: 49:59.

Hargreaves, J. N. G. and R. L. McCown. 1988. CERES-Maize: A versatile interactive version of CERES-Maize: CSIRO Trop. Agron. Technical. Mem/CSIRO Div. of Tropical Crops & Pastures, St. Luica. QLD. Australia.

Hodges, T., D. Botner, C. Sakamoto and J. H. Haug. 1987. Using CERES-Maize model to estimate production for the USA corn belt. Agric. For. Meteorol. 40: 293-303.

Jones, C. A. and J. R. Kiniry (ed). 1986. CERES-Maize: A simulation model of maize growth and development. Texas A &M Univ. press College Station.

Kiniry, J. M., J. R. Williams, R. L. Vanderlip, J. D. Atwood, D. C. Reicosky, J. Mulliken, W. J. Cox, H. J. Mascagni, Jr. S. E. Holliger and W. J. Wiebold. 1997. Evaluation of two maize models for nine U.S. locations. Agron J. 89: 421 - 426.

Kiniry, J. M. and A. J. Brockholt. 1998. Agronomic models, maize and sorghum simulation in diverse Texas environments. Agron J. 90: 682 - 687.

Kunkel, K. E., S. E. Hollinger and B. C. Reinke. 1994. Impact of Midwestern flooding on crop production. Midwestern Climate Ctr. State Water Survey. Champaign, IL.

Lamm, F. R., M. E. Nelson and D. H. Rogers. 1993. Resource allocations in corn production with water resource constraints. Applied Engineering in Agriculture 9(4): 379 - 385.

Lamm, F. R., D. H. Rogers and H. L. Manges. 1994. Irrigation scheduling with planned soil water depletion. Transactions of the ASAE 37(5): 1491 - 1497.

Lamm, F. R., T. P. Trooien, H. L. Manges and H. D. Sunderman. 2001. Nitrogen fertilization for subsurface drip irrigated corn. Transaction of the ASAE 44(3): 533 - 542.

Llewelyn, R. V. and A. M. Featherstone. 1997. A comparison of crop production functions using simulated data for irrigated corn in western Kansas. Agricultural Systems 54: 521 - 538.

Martin, E. C., J. T. Ritchie and T. L. Loudon. 1985. Use of the CERES-Maize model to evaluate irrigation strategies for humid regions. Advances in evaporation. pp. 342-350. In: Proceedings of the National Conference on Advances in Evapotranspiration. Chicago, Illinois, ASAE.

Musick, J. T. and D. A. Dusek. 1980. Irrigated corn yield response to water. Transactions of the ASAE 23(1): 92 - 98, 103.

Stegman, E. C. 1986. Efficient irrigation timing methods for corn production. Transactions of the ASAE 29(1): 203-210.

Stewart, J. I., R. D. Misra, W. O. Pruitt and R. M. Hagan. 1975. Irrigating corn and grain sorghum with a deficit water supply. Transactions of the ASAE 18(2): 270 - 280.

USDA, 1993. Irrigation water requirements. National engineering handbook. Ch. 2. Soil Conversation Service.