THE EFFECT OF MOISTURE STRESS ON CORN
PRODUCTION IN THE HIGH PLAINS

by

Report
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ABSTRACT

Evapotranspiration and yield were measured for selected deficit irrigation and nitrogen levels. The resulting data were used to derive the water-production function. Nitrogen stress limited yield but did not affect the water-production function relationship. However, water-production functions did vary in their intercept between years. These differences may have been due to differences in yearly soil evaporation. The slope of the water-production functions of the water use efficiency was the same over the years.

Corn growth was modeled using a physiologically based model. The model simulated biomass and grain yield under nonmoisture stress conditions within 10 percent of the measured values, but overestimated production as moisture stress increased.

Modifications to the model to include the effect of moisture stress on leaf size and the effect of hail damage on corn growth increased the model's predictability, but still, the model overestimates corn growth under soil moisture stress conditions. The model was unsatisfactory in predicting corn growth when competition between plants was decreased, due to the 1982 low planting density.

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INTRODUCTION

The southern High Plains of New Mexico contain productive, ground water-irrigated agricultural areas. However, the ground water sources have little or no recharge and are being depleted rapidly. Irrigation with ground water in the southern High Plains is an important part of the agricultural situation; however, it is considered a supplemental source of water for crop production. Precipitation, which occurs predominantly in the summer, has become an important component of the total water supply, especially because of increased energy costs to pump water.

Sufficient water is not always available to supply the needs for maximum evapotranspiration. Knowledge is needed concerning the amount of yield reduction associated with a unit reduction in applied irrigation water.

OBJECTIVES

The main research goal was to determine the water-production function for corn (Zea mays) and to incorporate that water-production function into a model capable of predicting the effect of irrigation strategies on yield reduction. Specifically, the objectives were:

1. To irrigate corn, using a sprinkler-line-source, with a decreasing total water application at selected levels of fertilizer application;
2. To measure the seasonal evapotranspiration and crop yield and to determine the crop-production function as derived from a water-yield-fertilizer relationship;

3. To develop a physiologically based corn model and verify its accuracy in the High Plains.

METHODS

The study site was located 24 kilometers north of Clovis, New Mexico, at the Plains Branch Experiment Station. The soil type at the site is a Pullman clay-loam (fine-loamy, mixed, Thermic Torretic Palenstall). Soil samples were taken in the corn plots and analyzed for texture. The data are presented in Table 1. The irrigation water quality was 0.421 mmhos/cm (Table 2).

Four corn plots, variety NKPX74, were planted April 10, 1980; April 14, 1981; and May 20, 1982, on 102 cm wide beds. Before planting, each of the four plots received different fertilizer applications of anhydrous ammonia which were 0, 224, and 336 kg/ha in 1980 and 0, 56, 112, and 168 kg/ha in 1981. Two plots planted in 1982 received 0 and 224 kg/ha. Figure 1 shows the layout of a single plot. Soil analysis showed 144 kg/ha, 174 kg/ha, and 97 kg/ha in 1980, 1981, and 1982 respectively, of residual nitrogen in the top 92 cm of the soil profile. This amount was added to the amount of fertilizer applied to obtain the total nitrogen available for plant growth.

Initially, a furrow irrigation brought the top meter of the root zone to field capacity. Emergence occured April 28, 1980, with a planting density of 58,700 plants per hectare; April 25, 1981 with a planting density of 60,000 plants per hectare; and on May 27, 1982, with a planting density of 47,684 plants per hectare.

Table 1. Soil texture analysis of the corn plots, 1981.

Fertilizer Treatment Number	Depth	Percent Clay	Percent Sand	Percent Silt	Texture
	cm				
1	0-23	32.4	37.2	30.4	Clay loam
1	23-38	38.4	34.8	26.8	Clay loam
1	38-61	34.6	38.8	26.6	Clay loam
1	61-91	30.8	46.4	22.8	Sandy clay loam
1	91 122	51.2	28.4	20.4	Clay
1	122-152	49.2	34.2	16.6	Clay
2	0-23	32.4	42.4	25.2	Clay loam
2	23-38	38.8	40.4	20.8	Clay loam
2	38-61	36.8	36.4	26.8	Clay loam
2	61-91	34.8	42.4	22.8	Clay loam
2	91-122	48.8	34.4	16.8	Clay
2	122-152	52.8	28.0	19.2	Clay
3	0-23	31.68	48.6	19.72	Sandy clay loam
3	23-38	35.4	45.0	19.6	Sandy clay
3	38-61	33.6	45.12	21.28	Clay loam
3	61-91	28.0	51.24	20.76	Sandy clay loam
3	91-122	43.8	46.32	9.88	Sandy clay
3	122-152	48.0	40.8	11.2	Clay
4	0-23	33.8	43.6	22.6	Clay loam
4	23-38	37.8	42.8	19.4	Clay loam
4	38-61	32.0	44.4	23.6	Clay loam
4	61-91	31.0	49.36	19.64	Sandy clay loam
4	91-122	27.6	42.0	30.4	Clay loam
4	122-152	39.6	36.0	24.4	Clay loam

Table 2. Irrigation water quality at Clovis, New Mexico.

		meq/1										
mmhos/cm EC	pH	Ca	Na	Mg	K	Tot Cat	Cl	Co_3	HCO_3	SO_4	Tot An	mg/1 NO_3-N
.421	8.44	1.98	1.93	.66	.14	4.71	.27	.40	2.00	1.92	4.59	1.80

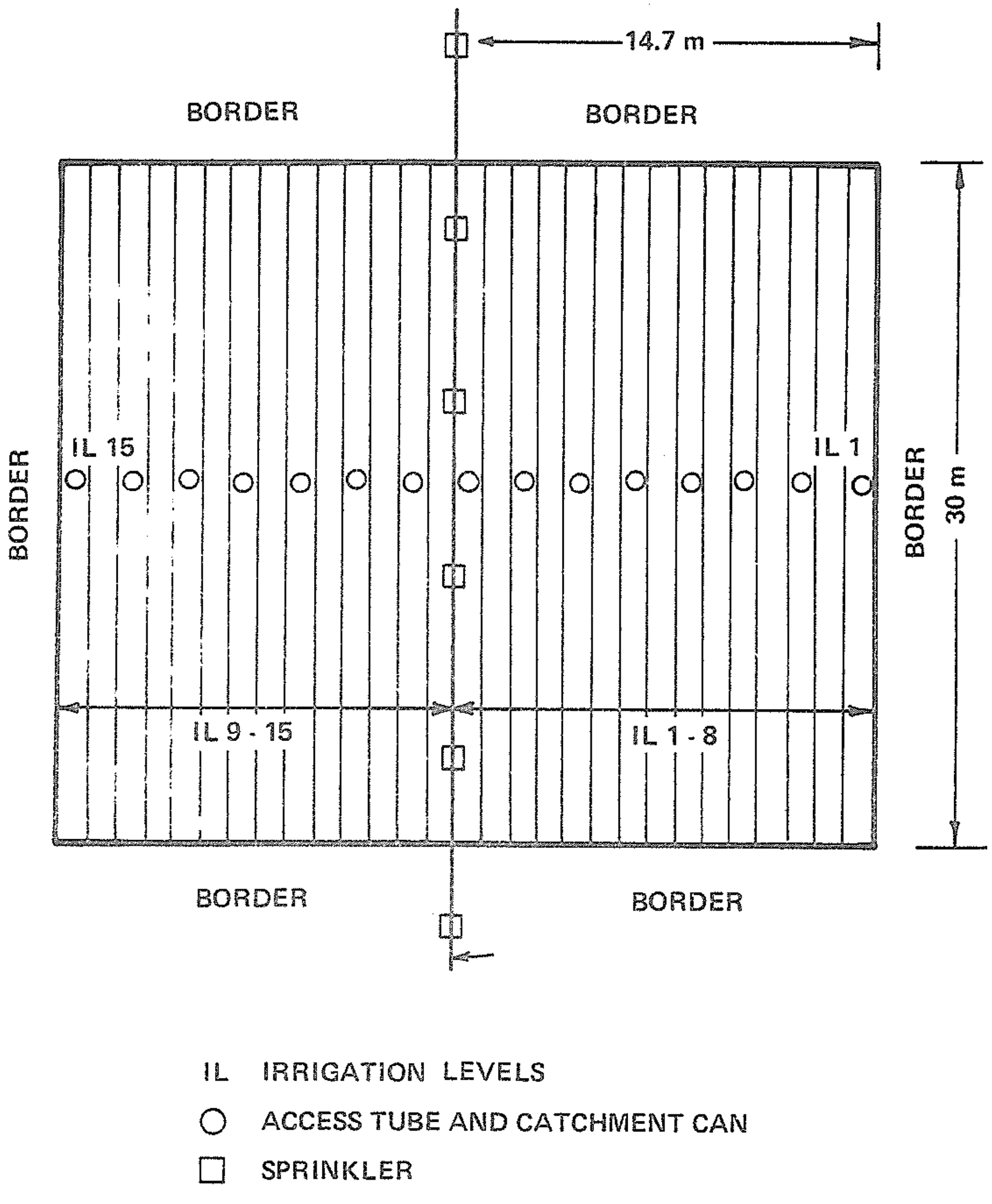

Figure 1. Details of the layout of the sprinkler-line-source.

The fields were subsequently irrigated using a sprinkler-line-source. This technique provides adequate water throughout the growing season near the sprinkler-line, and applies a decreasing water application perpendicular to the line. Sprinklers were spaced every 6.1 meters along the line and operated at 3 bars pressure, producing an effective radius of 15 meters. The system was operated late in the evening when winds were less than 3 kilometers per hour.

Evapotranspiration (E) was determined in every other row in each plot by determining the water balance at that location described by Equation 1:

$$E = I + R - D \pm \Delta S_m \qquad (1)$$

where:

I = irrigation (cm)

R = rainfall (cm)

D = drainage (cm)

ΔS_m = change in soil moisture (cm)

To measure irrigation (I), catchment cans were installed across the field in alternate rows at a spacing of 2.03 meters. Catchment cans were read after each irrigation and were raised as the crop grew so that they were 15 cm above the canopy. Rainfall (R) was measured using a Standard 20 cm rain gage located next to the plots. Drainage (D) was assumed to be negligible. Change in soil moisture (S_m) was determined from neutron soil-moisture readings. Neutron access tubes were installed adjacent to the catchment cans to a depth of 1.5 meters and soil-moisture measurements were taken biweekly throughout the growing season.

The corn was harvested on October 4, 1980, September 20, 1981, and October 6, 1982. The harvest plots were located on each row. Three replications were taken down the row, each 9.1 meters long, making a total of 27.3 meters of harvest material for each water balance determined. Evapotranspiration was determined in 1980 by interpolation between the rows where yield, but not evapotranspiration, was measured. Weather data were measured at a nearby weather station. The data included solar radiation, maximum-minimum humidity, 24-hour wind run, pan evaporation, and rainfall.

The climatic data variables were used as input variables to the hydrologically based dynamic corn growth model developed by Stapper and Arkin (1980). A flow chart of the model is presented in Appendix D.

Methods and Materials Used in Taking Biomass Samples

Biomass samples were taken on four separate dates during the growing period. A rectangular metal frame having an inside area of 1.2 m^2 and a width equal to the plant row spacing was utilized until plant size in July restricted its use. A ruler then was used to measure an equal area. The frame was laid directly on top of the planting bed with the length of the frame lying parallel to the bed length. All plants rooted within the area of the frame were cut off at the soil surface and removed from the field to determine their above ground weight.

In 1980, a sample size of 1.0 m^2 was harvested; 0.63 m^2 was harvested in 1981 and 1982. This corresponded to 7, 6, and 3 plants at each sample time. Biomass samples were taken on both sides of the sprinkler-line in each of the plots and at distances approximately 2, 6, 10, and 14 meters away from the line. The samples were taken outside the 9.1 meter subplots that were to be harvested but yet within the zone of maximum sprinkler overlap. Immediately after sampling, the plants were separated into leaves (above ligule), stem, ear husk and shank, cob, and grain. The wet (field) weights of each component per sample were obtained as soon as possible after separation. Dry weights measurements of the same samples were made after at least 48 hours of oven drying at 80°C. As plant size increased, drying time was extended to 72 hours.

Procedures Used in Determination of Leaf-Area-Index (LAI)

Before oven drying, representative subsamples of leaf matter were obtained from plants taken in the biomass samples discussed above. The leaf segments sampled were laid out and traced on a sheet of graph or botany paper of a known density (g/cm^2) The "paper leaves" were then cut out and weighed on a sensitive torsion balance. Leaf area was determined from this procedure. The actual plant dry-leaf-density also was determined after oven drying the leaf matter. Utilizing this density, leaf area per unit ground area (L_{AI}) was calculated from the biomass data. A representative biomass sample consisted of 7 plants in 1980, 6 plants in 1981, and 3 plants in 1982. Thus, average leaf area per plant and weight per plant were also determined.

Grain was harvested at maturity using a combine, and by hand sampling a 1.5 meter strip between plots. Growing-degree-days (G) for corn are based upon Equation 2:

$$G = (\text{max temp} + \text{min temp})/2 - \text{Base T} \qquad (2)$$

where:

max temp = maximum daily temperature $^{\circ}C$
min temp = minimum daily temperature $^{\circ}C$
Base T = base temperature

The base temperature is $10^{\circ}C$ for corn. The maximum cut off temperature is $30^{\circ}C$, which is substituted for the daily maximum temperature when it exceeds that temperature. When the daily minimum temperature is lower than the base temperature, a sine curve is used to approximate the diurnal change in temperature between maximum and minimum (Stapper and Arkin, 1980). Growing-degree-days also are modified by a day length function (D) and solar reduction factor by Stapper and Arkin, (1980). The G in subsequent tables are those computed by the corn model (Stapper and Arkin, 1980), and include the discussed modifications to Equation 2.

RESULTS AND DISCUSSION

The applied water for each plot is presented in Appendix A. Tables 3, 4, and 5 and Figure 2 present the grain yield and measured evapotranspiration for the corn plots receiving different levels of fertilizer. Table 6 presents the water-production function for each fertilizer treatment.

Table 3. Grain yield and evapotranspiration (E) and harvest ratio (HR) of corn irrigated using a sprinkler-line-source, 1980.

Irrigation Level	Fertilizer Level															
	Plot 1 0 kg/ha				Plot 3 112 kg/ha				Plot 2 224 kg/ha				Plot 4 336 kg/ha			
	E	Grain1/	Biomass2/	HR	E	Grain	Biomass	HR	E	Grain	Biomass	HR	E	Grain	Biomass	HR
	cm	kg/ha	kg/ha		cm	kg/ha	kg/ha		cm	kg/ha	kg/ha		cm	kg/ha	kg/ha	
1.	39.6	231	4308	.05	43.4	246	4442	.05	39.3	103	3108	.03	39.2	58	3683	.02
1a.	41.9	166			47.0	294			41.9	120			43.2	193*		
2.	44.9	111			50.0	587			44.3	116			47.9	591		
2a.	49.2	150			54.1	879			50.8	334			52.8	800		
3.	52.5	419	4408	.10	57.8	1799	6092	.29	57.5	610	6983	.09	58.8	2074	8600	.24
3a.	62.2	795			63.5	2493			63.5	1452			64.8	2596		
4.	70.2	1519			68.9	4152			69.5	3543			70.8	4551		
4a.	73.7	2377			73.7	5483			77.5	5262			77.5	6081		
5.	76.8	6525	12517	.52	78.6	4427	16983	.26	87.4	8197	15941	.51	83.3	6871	18950	.36
5a.	82.6	8505			82.0	7458			91.4	8715			86.4	8665		
6.	89.7	9200			86.1	8208			96.5	9763			91.2	8699		
6a.	88.9	9280			89.0	8494			97.8	8803			91.4	8212		
7.	92.4	9358	19000	.49	93.7	9959	18408	.54	98.6	9573	18533	.52	94.0	8879	22042	.40
7a.	94.0	8125			99.0	10172			99.1	9314			96.5	8656		
8.	95.9	9264			103.7	9009			100.5	9556			100.5	9702		
8a.	94.0	8478			99.1	8932			99.1	8847			95.3	8852		
9.	90.3	9748	21733	.45	97.3	9935	18658	.53	97.8	9219	16933	.54	94.0	8954	21808	.41
9a.	89.0	9039			96.5	9952			95.3	9695			90.2	8544		
10.	89.3	8969			95.9	8489			91.1	8234			86.4	7825		
10a.	82.6	7153			89.0	8367			82.6	6856			83.8	8760		
11.	79.2	7992	15283	.52	83.8	7772	21158	.36	75.1	5402	12950	.42	78.4	4806	19425	.24
11a.	73.7	5680			76.5	6895			72.4	4345			72.4	2416		
12.	70.4	4219			71.0	4922			64.7	2835			65.4	889		
12a.	64.8	2630			64.8	2906			58.4	1783			59.7	782		
13.	59.0	1372	6550	.20	60.5	1141	12400	.09	53.1	1024	6325	.16	54.4	456	5250	.09
13a.	54.4	662			55.9	477			49.5	501			50.3	120		
14.	49.6	521			48.8	319			46.4	256			46.3	123		
14a.	44.5	129			45.7	123			41.9	180			43.2	120		
15.	40.6	36	2250	.02	43.8	102	5342	.02	36.7	101	3908	.03	39.5	518	2192	.23

1/ Grain yield at 14.5 percent moisture.

2/ Biomass yield at 0 percent moisture.

a. The a represents interpolated E values and measured yield values.

Table 4. Grain yield and evapotranspiration (E) of corn irrigated using a sprinkler-line-source, 1981.

	Fertilizer Level							
Irrigation Level	Plot 4 0 kg/ha		Plot 3 56 kg/ha		Plot 1 112 kg/ha		Plot 2 168 kg/ha	
	E	Grain#	E	Grain#	E	Grain#	E	Grain#
	cm	kg/ha	cm	kg/ha	cm	kg/ha	cm	kg/ha
1	66.6	6265	62.7	3959	66.7	5835	61.2	5225
2	65.8	7037	62.9	5450	67.5	7438	62.9	4888
3	68.6	6870	65.5	5678	68.9	7137	64.6	5412
4	70.4	6467	67.9	6349	70.3	6711	65.4	5770
5	70.8	6642	70.3	7070	72.1	8346	66.5	7413
6	75.0*	6204*	66.2	7346	72.9	7818	69.4	7618
7	76.8*	7098*	76.1*	7950*	73.9	7691	72.3	8320
8	76.7*	7679*	78.9*	7722*	73.4	7567	73.9	7747
9	77.2*	7489*	78.0*	7389*	73.4	6795	71.0	7764
10	69.7	6620	72.3	7035	70.0	7144	72.8	7218
11	67.9	6054	68.1	6321	66.8	5760	66.8	6607
12	64.4	5704	64.3	6363	62.2	4556	64.4	6022
13	63.7	4965	64.5	6065	62.1	4588	61.9	5883
14	62.8	4240	63.1	5253	60.9	4496	63.6	5269
15	63.1	4838	63.8	4404	60.7	4698	64.5	4239

Grain yield at 14.5 percent moisture.

* Over-irrigated due to limited growth by nitrogen stress causing drainage to be included in E calculation. Data not used in the evaluation of the water-production functions.

Table 5. Grain yield evapotranspiration (E) and harvest ratio (HR) of corn irrigated using a sprinkler-line-source, 1982.

	Fertilizer Level							
	Plot 2				Plot 1			
	0 kg/ha				224 kg/ha			
Irrigation Level	E	Grain*	Biomass#	HR	E	Grain*	Biomass#	HR
	cm	kg/ha	kg/ha		cm	kg/ha	kg/ha	
1	45.6	4790	13220	.36	53.7	5427	13764	.39
2	42.7	5439			53.3	5898		
3	48.5	5834	10830	.54	53.0	7197	14512	.49
4	48.9	5949			54.7	8063		
5	51.9	6955	15940	.44	59.0	7987	18336	.44
6	52.7	6535			64.2	9579		
7	53.3	6599	17810	.37	66.5	8866	21606	.41
8	58.0	6624			65.5	9732		
9	53.0	6051			64.4	8305		
10	50.7	6382			63.6	8942		
11	53.4	7044			59.8	8127		
12	51.2	6369			56.4	8586		
13	51.0	6407			55.3	7821		
14	51.4	6140			51.3	6790		
--	----	----			52.1	5745		

* Grain yield is at 14.5 percent moisture.

\# Biomass yield is at 0 percent moisture.

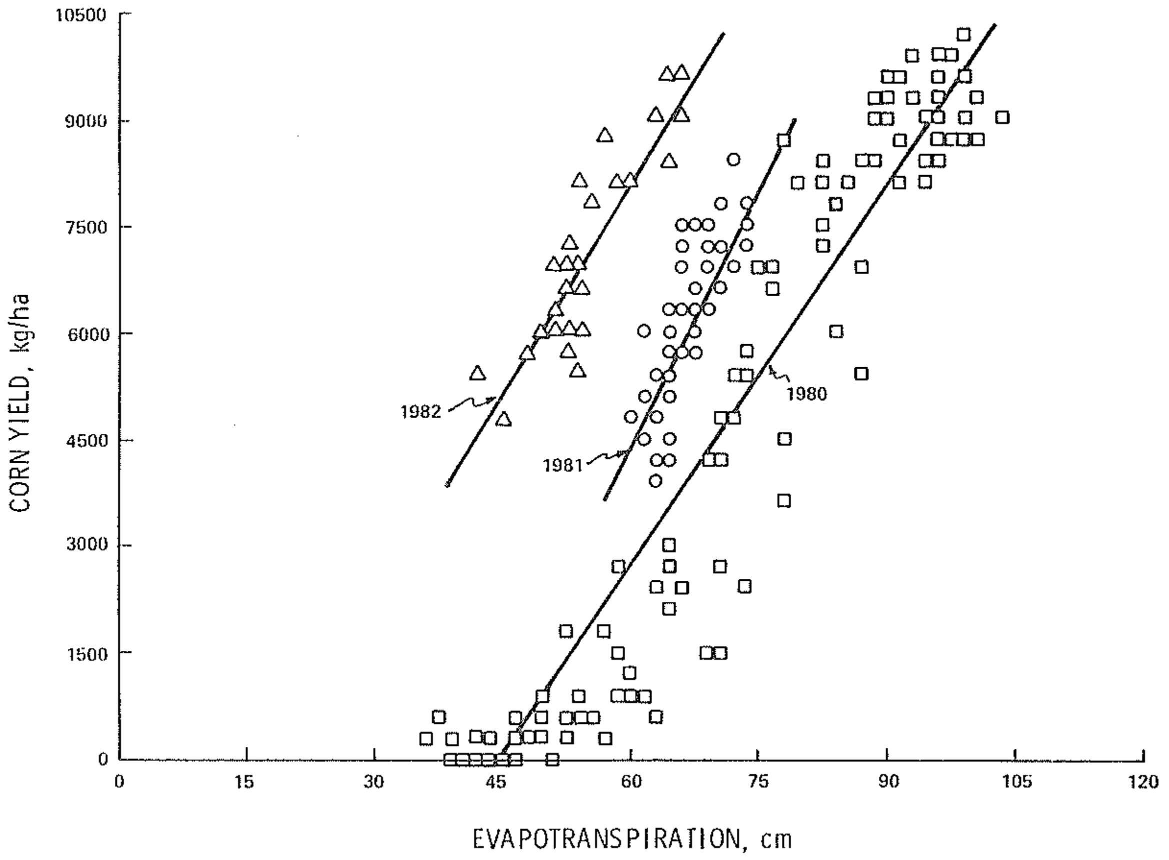

Figure 2. A plot of the corn water-production functions for 1980, 1981, and 1982 at Clovis, New Mexico.

Table 6. Linear water-production functions for corn at four levels of fertilizer applications, 1980, 1981, and 1982.

Equation Number	Fertilizer Level Applied	Water-Production Functions	Coefficient of Determination
	kg/ha	kg/ha cm	
1980			
1	0	Y = -9128 + 195.2 E 1/	.90a
2	112	Y = -8826 + 188.7 E	.95a
3	224	Y = -7770 + 173.2 E	.96a
4	336	Y = -8371 + 181.1 E	.92a
5	Combined Data	Y = -8499 + 183.5 E	.93
6	Combined Data	Y = -3590 + 143.68 W 2/	.91
7	Combined Data	Y(Biomass) = -9315 + 309.8 E 3/	.90
1981			
8	0	Y = - 9852 + 236.6 E	.60a
9	56	Y = -10563 + 250.2 E	.55a
10	112	Y = -11077 + 257.1 E	.84a
11	168	Y = -10656 + 254.9 E	.71a
12	Combined Data	Y = -10662 + 251.8 E	.71
13	168	Y = -70224 + 212.1 W	.77
		Y(Biomass) = No correlation between total dry weight and E due to hail damage. $r^2 = 0.04$	

(continued)

Table 6. (continued)

Equation Number	Fertilizer Level Applied	Water-Production Function	Coefficient of Determination
	kg/ha	kg/ha cm	
1982			
14	0	$Y = -172 + 125.7\ E$	.61a
15	224	$Y = -4213 + 206.4\ E$	.68a
16	Combined Data	$Y = -3639 + 195.3\ E$	.77
17	0	$Y = 4187 + 56.7\ W$	.44b
18	224	$Y = 2587 + 136.4\ W$	.83c
19	Combined Data	$Y(\text{Biomass}) = -16180 + 572.5\ E$ 4/	.97
20a	Combined Data	$Y = -8546 + 184.9\ E$ (1980)	.92
20b	over years have	$Y = -6176 + 184.9\ E$ (1981)	
20c	a common slope only	$Y = -3066 + 184.9\ E$ (1982)	
1980:	Combined Data	$H_r = -0.28 + .0082\ E$	.83
1981:	No Average Data	$r^2 = .007$	

1/ E = evapotranspiration; Y = grain yield at 14.5 percent moisture.

2/ W = applied water + precipitation.

3/ Y(Biomass) = total biomass at 0 percent moisture.

4/ Only 224 kgN/ha plot.

The maximum yield at the sprinkler-line was around 9,000 kg/ha for all four plots in 1980. These yields indicate that nitrogen was not a limiting variable, even in the plot receiving no application of nitrogen. The maximum evapotranspiration measured in Plot 3 was 103.7 cm, which produced 9,009 kg/ha of grain yield. Because it was a dry year (Table 7) yield at the edge of the field was on an average only 160 kg/ha. Thus, a large range of values for yield and E used to derive the water-production functions were obtained.

Hail on August 8, 1981, damaged leaves and productivity. Yield was 8,000 kg/ha at the line. Because of the wet year, (Table 7), only two sprinkler irrigations were applied. The yield at the edge of the field was approximately 5,000 kg/ha. The lack of range in yield resulted in reduced coefficients of determination in the derived water production functions.

Plots 3 and 4 in 1981 had limited yields at the line due to nitrogen stress. Consequently, the data collected near the line included deep seepage and so was not included in the water-production analysis. However, the resulting water-production functions were statistically the same as those from the nonstressed lots, indicating that nitrogen limits growth but does not change the relationship between ET and yield.

The 1982 corn growing season was again a wet year and resulted in low coefficients of determination for the water-production functions. There was no statistical ($P \leq 0.05$) difference between plots even though the unfertilized plot had reduced yields substantially compared to the fertilized plot. Table 6 presents the combined water-production functions over the years. The functions had common slopes but different intercepts.

Table 7. Monthly precipitation during the growing season for Clovis corn. Three seasons: 1980, 1981, and 1982; compared to the average long-term precipitation.

Month and Crop Growth Period	Average Precip-itation	Measured Precipitation		
		1980	1981	1982
	cm	cm	cm	cm
	1951-1980			
April	1.91	0.25 (4/11-4/30)	2.36 (4/14-4/30	0
May	4.50	6.48	4.14	5.66 (5/20-5/31)
June	5.79	0.28	6.83	5.38
July	7.47	0.46	13.03	13.46
August	6.42	5.00	27.02	4.21
September	4.50	4.97	6.24	2.20
October	3.30	0 (10/1-10/4)	0	1.82 (10/1-10/6)
Totals	33.89	17.45	59.64	32.76

Year	Planted	Harvested
1980	4/11	10/04
1981	4/14	09/25
1982	5/20	10/06

The intercepts represent that portion of E that evaporated from the soil and transpired from the plant to produce the minimum plant growth required for grain yield. The intercept ranged from 46 cm in 1980 to 16.5 cm in 1982. When soil evaporation was modeled and subtracted from the measured E, the resulting transpiration versus grain yield functions had intercepts that were close together but still statistically different. In future work, soil evaporation needs to be measured to determine if a common intercept will result when yield is a function only of transpiration.

The 144 kg/ha of residual nitrogen in the soil profile in 1980 was sufficient to supply the nitrogen needs of the plant. The additional nitrogen that the other plots received served no purpose. Because fertilizer was not a factor in all four of the plots in 1980, there were four repetitions of the sprinkler-line study. It is interesting to note that the coefficient of determination for the plots ranged from 0.90 to 0.95. Although in 1981 there was a residual of 174 kg/ha of nitrogen, plots 3 and 4 did show a nitrogen stress yield difference. The rain may have pushed the nitrogen into the lower portion of the soil profile where it was not readily available. In 1982, a reduction in yield occurred in the plot receiving no nitrogen and having only 97 kg/ha of residual nitrogen. Statistically, ($P \leq 0.05$) the linear equations for the different fertilizer levels in 1981 and 1982 are the same. This indicated that nitrogen stress, when it occurred, reduced both yield and E equally. Consequently, the water-production function is independent of nitrogen level except to limit the maximum yield obtainable.

Figures 3, 4, and 5 show a plot of the applied water-production function and the combined evapotranspiration water-production function.

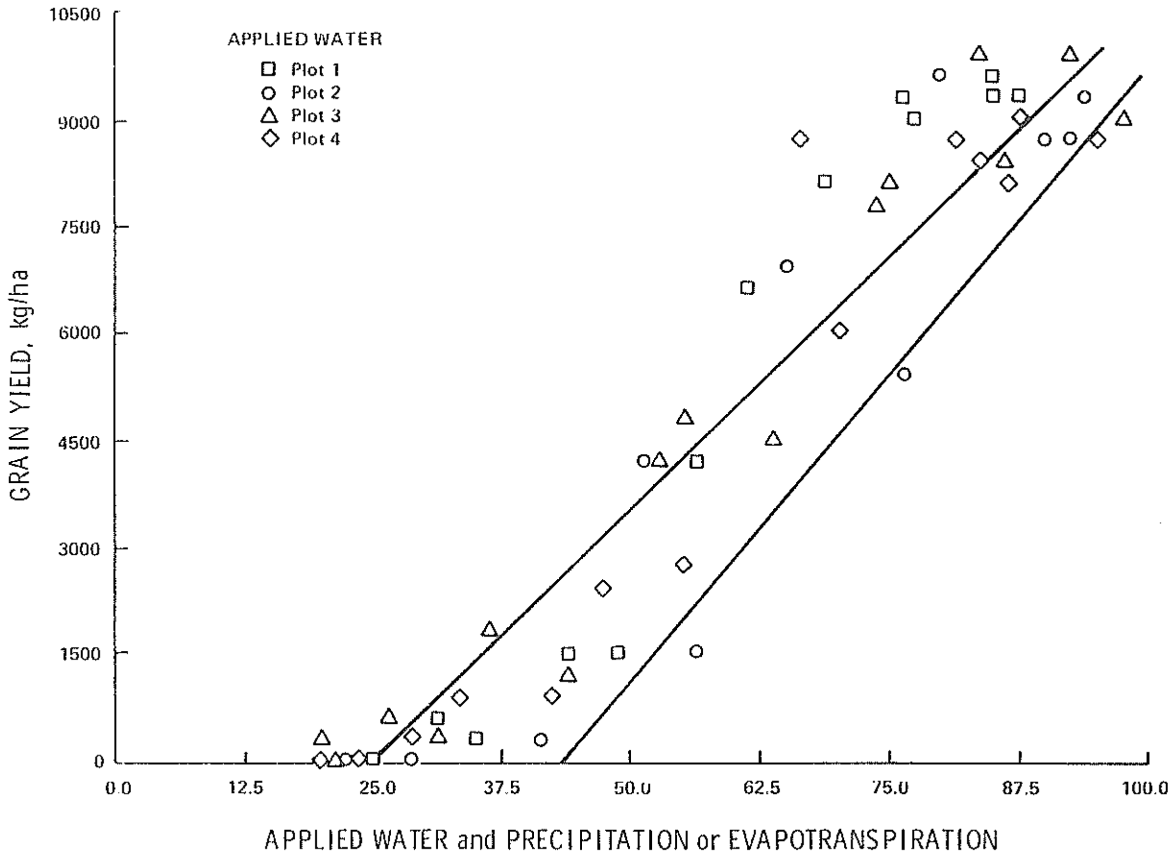

Figure 3. Combined applied water-production function and evapotranspiration water-production function in 1980.

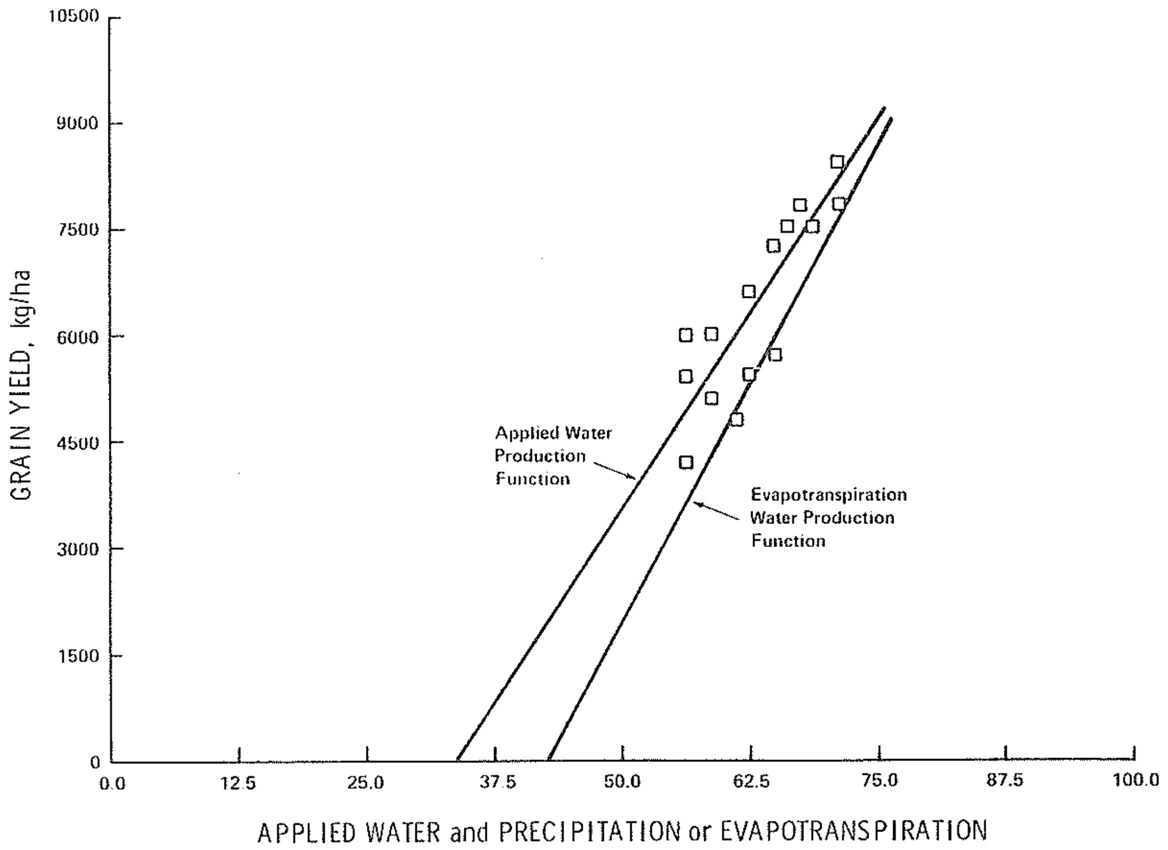

Figure 4. Applied water-production function and evapotranspiration water-production function in 1981, for the corn plot receiving 168 kg/ha of fertilizer.

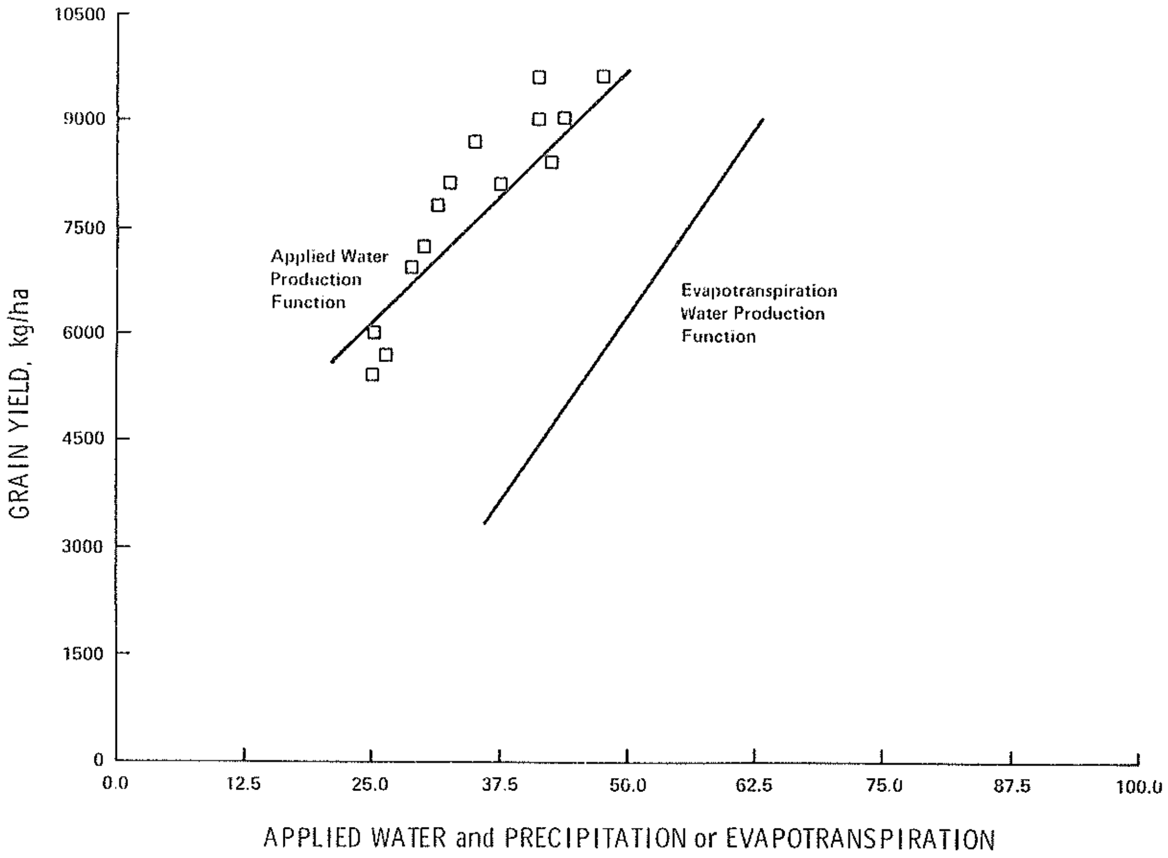

Figure 5. Applied water-production function and evapotranspiration water-production function in 1982, for the corn plot receiving 224 kgN/ha.

The slope of the evapotranspiration water-production function is steeper than the applied water-production function, indicating that as the plants become stressed they will remove a greater percent of the soil moisture reservoir. This finding shows the importance of having a full water supply at the beginning of the irrigation season. As the plants become moisture stressed, they can remove water from the soil moisture reservoir to increase seasonal evapotranspiration.

Physiology of the Corn Plant

Tables 8, 9, 10, 11, 12 and 13 present the dates that phenological events occurred for corn from planting to harvest. There was a suppression of physiological development under moisture stress. This suppression of crop development was not a constant correllating to the number of G. It varied throughout the growing season, averaging a suppression of 250 G for the appearance of leaf ligule numbers 9 through 20 in 1980, 50 G suppression of leaf numbers 10 through 20 in 1981 and 1982 when moisture stress was least (Figure 6). The suppression also was not a constant rate throughout the growing season due to the competition for moisture between individual plants on the edge of the field. As the crop develops, variability in stage development occurs on the edge of the field due to this competition. The plants mature at a uniform rate in the center of the field.

Hail damage in 1980 occurred between the appearance of ligules 2 and 3, but did not appear to suppress physiological development. Hail damage on August 9, 1981, reduced the plant biomass by 25 percent. No hail damage occurred in 1982.

Table 8. A chronology of phenological events for corn located at the sprinkler-line-source in Clovis, New Mexico, 1980. Fertilized with 224 kg/ha.

Dates [1]			Days After Emergence	Event
Calendar	Julian	G*		
10 Apr 80	101		- 13	Planted
23 Apr 80	114	80	0	Emerged
30 Apr 80	121	117	7	Leaf ligule 1
07 May 80	128	156	14	Leaf ligule 2
08 May 80	129		15	Hail damage
17 May 80	138	217	24	Leaf ligule 3
24 May 80	145	274	31	Leaf ligule 4
28 May 80	149	321	15	Leaf ligule 5
01 Jun 80	153	371	39	Adventitious roots
03 Jun 80	155	395	41	Leaf ligule 6
09 Jun 80	161	474	47	Leaf ligule 7
10-12 Jun 80	162-164	515	48-50	Tassel initiation
13 Jun 80	165	529	51	Leaf ligule 8
16 Jun 80	168	573	54	Leaf ligule 9
20 Jun 80	172	635	58	Leaf ligule 10
27 Jun 80	179	742	65	Leaf ligule 11
29 Jun 80	181	775	67	Leaf ligule 12
30 Jun 80	182	789	68	Leaf ligule 13
02 Jul 80	184	822	70	Leaf ligule 14
03 Jul 80	185	837	71	Leaf ligule 15
07 Jul 80	189	897	75	Leaf ligule 16
09 Jul 80	191	929	77	Leaf ligule 17
10 Jul 80	192	943	78	Leaf ligule 18
10 Jul 80	192	983	78	Most tassels visible
11 Jul 80	193	957	79	Leaf ligule 19
14 Jul 80	196	1002	82	Leaf ligule 20
14 Jul 80	196	1002	82	Most silks visible (Anthesis)
26 Jul 80	208	1180	94	Blister
07 Aug 80	220	1356	106	Dough
25 Aug 80	238	1589	124	Dent (early)
06 Sep 80	250	1729	136	Full dent
04 Oct 80	278	1941	164	Harvest

[1] The above chronology of growth was observed at the line. As distance from the line increased, suppression of growth occurred.
ie. 16 Jun 80 -- visible leaf ligules at plot edges; 8
27 Jun 80 -- visible leaf ligules at plot edges; 8
3 Jul 80 -- visible leaf ligules at plot edges; 9
14 Jul 80 -- leaf ligules at edge = 11-15; also, no tassels clearly visible
29 Jul 80 -- leaf ligules at edge = 19-20; however, plant height and leaf sizes greatly reduced

*Growing-degree-day

Table 9. A chronology of phenological events for corn located at the sprinkler-line-source in Clovis, New Mexico, 1981. Fertilized with 168 kgN/ha.

Dates Calendar	Julian	G*	Days After Emergence	Event
14 Apr 81	104		- 11	Planted
25 Apr 81	115		0	Emergence
28 Apr 81	118	105	3	Leaf ligule 1
03 May 81	123	156	8	Leaf ligule 2
09 May 81	129	200	14	Leaf ligule 3
15 May 81	135	241	20	Leaf ligule 4
24 May 81	144	311	29	Leaf ligule 5
28 May 81	148	355	33	Leaf ligule 6
01 Jun 81	152	388	37	Tassel initiation
03 Jun 81	154	417	39	Leaf ligule 7
08 Jun 81	159	470	44	Leaf ligule 8
15 Jun 81	166	570	51	Leaf ligule 9
20 Jun 81	171	631	56	Leaf ligule 10
22 Jun 81	173	665	58	Leaf ligule 11
23 Jun 81	174	681	59	Leaf ligule 12
25 Jun 81	176	713	61	Leaf ligule 13
27 Jun 81	178	741	63	Leaf ligule 14
30 Jun 81	181	782	66	Leaf ligule 15
02 Jul 81	183	812	68	Leaf ligule 16
04 Jul 81	185	843	70	Leaf ligule 17
05 Jul 81	186	856	71	Leaf ligule 18
06 Jul 81	187	871	72	Leaf ligule 19
07 Jul 81	188	885	73	Tassels visible
08 Jul 81	189	900	74	Leaf ligule 20
09 Jul 81	190	911	75	Anthesis
20 Jul 81	201	1074	86	Blister (approx.)
21 Aug 81	233	1489	118	Early dent (beginning)
25 Aug 81	237	1536	122	0.50 dent
27 Aug 81	239	1559	124	Full dent
20 Sep 81	263	1773	188	Harvest

*Growing-Degree-Day

Table 10. A chronology of phenological events for corn located at the sprinkler-line source in Clovis, New Mexico, 1982. Fertilized with 224 kgN/ha.

Calendar	Julian	G*	Days After Emergence	Event	Leaf Size cm^2
20 May 82	140		-7	Planted	
27 May 82	147	80	0	Emergence	
31 May 82	151	119	4	Leaf #1 at max.	6.1
04 Jun 82+	155	158	8	Leaf #2 at max.	11.4
07 Jun 82	158	201	11	Leaf #3 at max.	19.3
11 Jun 82	162	246	15	Leaf #4 at max.	39.5
16 Jun 82	167	301	20	Leaf #5 at max.	84.4
20 Jun 82	171	339	24	Leaf #6 at max.	144.5
25 Jun 82	176	404	29	Leaf #7 at max.	225.9
25 Jun 82+	176	404	29	Tassel initiation	
01 Jul 82	182	484	35	Leaf #8 at max.	355.8
04 Jul 82	185	528	38	Leaf #9 at max.	546.3
04 Jul 82+	185	528	38	Ear initiation	
07 Jul 82+	188	570	41	Leaf #10 at max.	693.5
09 Jul 82	190	600	43	Leaf #11 at max.	785.4
12 Jul 82	193	636	46	Leaf #12 at max.	891.3
12 Jul 82	193	636	46	Leaves 1-3 dead	
14 Jul 82	195	665	48	Leaf #13 at max.	938.7
17 Jul 82+	198	713	51	Leaf #14 at max.	946.6
19 Jul 82	200	745	53	Leaf #15 at max.	919.2
20 Jul 82	201	760	54	Leaf #16 at max.	805.7
20 Jul 82	201	760	54	Leaves 1-5 dead	
22 Jul 82	203	791	56	Leaf #17 at max.	726.0
23 Jul 82	204	806	57	Leaf #18 at max.	626.2
26 Jul 82	207	849	60	Leaf #19 at max.	433.4
27 Jul 82	208	864	61	Tassel emergence	
28 Jul 82	209	875	62	Leaf #20 at max.	204.9
29 Jul 82	210	889	63	Anthesis	
02 Aug 82	214	941	67	Blister	
10 Aug 82	222	1051	75	Leaves 1-6 dead	
30 Aug 82	242	1315	95	Leaves 1-7 dead	
07 Sep 82	250	1416	103	Beginning of dent	
10 Sep 82	253	1450	106	Leaves 1-8 dead	
12 Sep 82	255	1473	108	Full dent	
17 Sep 82	260	1514	113	Leaves 1-9 dead	
22 Sep 82**	265	1544	118	Maturity	
24 Sep 82	267	1562	120	Leaves 1-10 dead	
06 Oct 82	279	1653	132	Harvest (leaf area near zero)	

* Growing-Degree-Day

\+ Estimates

** Estimate based on the absence of change in the following ratio: Dry Grain Weight/Dry Ear Weight (cob and grain).

Table 11. A chronology of phenological events for corn located at the edge of the sprinkler-line-source in Clovis, New Mexico, 1982. Fertilized with 224 kgN/ha.

Calendar	Julian	G*	Days After Emergence	Event	Leaf Size
					cm^2
20 May 82	140		-7	Planted	
27 May 82	147	80	0	Emergence	
31 May 82	151	119	4	Leaf #1 at max.	6.1
04 Jun 82+	155	158	8	Leaf #2 at max.	11.4
07 Jun 82	158	201	11	Leaf #3 at max.	19.3
11 Jun 82	162	246	15	Leaf #4 at max.	39.5
16 Jun 82	167	301	20	Leaf #5 at max.	84.4
20 Jun 82	171	339	24	Leaf #6 at max.	144.5
25 Jun 82	176	404	29	Leaf #7 at max.	225.9
25 Jun 82+	176	404	29	Tassel initiation	
01 Jul 82	182	484	35	Leaf #8 at max.	355.8
04 Jul 82	185	528	38	Leaf #9 at max.	546.3
04 Jul 82+	185	528	38	Ear initiation	
07 Jul 82+	188	570	41	Leaf #10 at max.	693.5
09 Jul 82	190	600	43	Leaf #11 at max.	785.4
12 Jul 82	193	636	46	Leaf #12 at max.	891.3
12 Jul 82	193	636	46	Leaves 1-3 dead	
14 Jul 82	195	665	48	Leaf #13 at max.	872.5
17 Jul 82+	198	713	51	Leaf #14 at max.	877.3
19 Jul 82	200	745	53	Leaf #15 at max.	836.5
20 Jul 82	201	760	54	Leaf #16 at max.	773.1
20 May-20 July	Same as at line.		Except leaf size, see leaf size table.		
22 Jul 82	203	791	56	Leaves 1-4 dead	
23 Jul 82	204	806	57	Leaf #17 at max.	665.3
25 Jul 82	206	835	59	Leaf #18 at max.	529.6
28 Jul 82	209	875	62	Leaf #19 at max.	357.4
28 Jul 82	209	875	62	Tassel emergence	
30 Jul 82	211	899	64	Leaf #20 at max.	142.8
02 Aug 82	214	941	67	Anthesis	
10 Aug 82	222	1051	75	Leaves 1-6 dead	
30 Aug 82	242	1315	95	Leaves 1-8 dead	
03 Sep 82	246	1368	99	Beginning of dent	
10 Sep 82	253	1450	106	Leaves 1-13 & 20 dead	
10 Sep 82	253	1450	106	Full dent (>50%)	
17 Sep 82	260	1514	113	Leaves 1-13 & 20 dead	
17 Sep 82+	260	1514	113	Maturity	
24 Sep 82**	267	1562	120	Leaves 1-14 & 18-20 dead	
06 Oct 82	279	1653	132	Harvest	

* Growing-Degree-Day

\+ Estimate

** Plus various fractional components of leaves 15-17.

Table 12. A chronology of phenological events for corn located at the sprinkler-line-source in Clovis, New Mexico, 1982. Unfertilized.

Calendar	Julian	G*	Days After Emergence	Event	Leaf Size
					cm^2
20 May 82	140		-7	Planted	
27 May 82	147	80	0	Emergence	
31 May 82	151	119	4	Leaf #1 at max.	6.1
04 Jun 82+	155	158	8	Leaf #2 at max.	11.9
07 Jun 82	158	201	11	Leaf #3 at max.	20.5
11 Jun 82	162	246	15	Leaf #4 at max.	39.1
16 Jun 82	167	301	20	Leaf #5 at max.	79.9
20 Jun 82	171	339	24	Leaf #6 at max.	140.9
25 Jun 82+	176	404	29	Leaf #7 at max.	
25 Jun 82	176	404	29	Tassel initiation	
01 Jul 82	182	484	35	Leaf #8 at max.	363.8
04 Jul 82	185	528	38	Leaf #9 at max.	495.0
04 Jul 82+	185	528	38	Ear initiation	
07 Jul 82	188	570	41	Leaf #10 at max.	606.2
09 Jul 82	190	600	43	Leaf #11 at max.	608.7
12 Jul 82	193	636	46	Leaf #12 at max.	713.1
12 Jul 82	193	636	46	Leaves 1-3 dead	
14 Jul 82	195	665	48	Leaf #13 at max.	723.1
17 Jul 82	198	713	51	Leaf #14 at max.	754.1
19 Jul 82	200	745	53	Leaf #15 at max.	665.7
20 Jul 82	201	760	54	Leaf #16 at max.	686.3
20 Jul 82	201	760	54	Leaves 1-5 dead	
22 Jul 82	203	791	56	Leaves 1-6 dead	
22 Jul 82	203	791	56	Leaf #17 at max.	583.8
23 Jul 82	204	806	57	Leaf #18 at max.	402.0
26 Jul 82	207	849	60	Leaf #19 at max.	276.5
27 Jul 82	208	864	61	Tassel emergence	
28 Jul 82	209	875	62	Leaf #20 at max.	129.3
29 Jul 82	210	889	63	Anthesis	
10 Aug 82	222	1051	75	Leaves 1-8 dead	
31 Aug 82	243	1329	96	Leaves 1-8 dead	
07 Sep 82	250	1416	103	Beginning of dent	
10 Sep 82	253	1450	106	Leaves 1-11 & 1/2 of 12 are dead	
12 Sep 82	255	1473	108	Full dent	
17 Sep 82	260	1514	113	Leaves 1-12 dead	
22 Sep 82	265	1544	118	Maturity	
24 Sep 82	267	1562	120	Leaves 1-12 dead	
06 Oct 82	279	1653	132	Harvest (leaf area near zero)	

* Growing-Degree-Day

\+ Estimates

Table 13. A chronology of phenological events for corn located at the edge of the sprinkler-line-source in Clovis, New Mexico, 1982. Unfertilized.

Calendar	Julian	G*	Days After Emergence	Event	Leaf Size cm^2
20 May 82	140		-7	Planted	
27 May 82	147	80	0	Emergence	
31 May 82	151	119	4	Leaf #1 at max.	6.1
04 Jun 82+	155	158	8	Leaf #2 at max.	11.9
07 Jun 82	158	201	11	Leaf #3 at max.	20.5
11 Jun 82	162	246	15	Leaf #4 at max.	39.1
16 Jun 82	167	301	20	Leaf #5 at max.	79.9
20 Jun 82	171	339	24	Leaf #6 at max.	140.9
25 Jun 82+	176	404	29	Leaf #7 at max.	
25 Jun 82	176	404	29	Tassel initiation	
01 Jul 82	182	484	35	Leaf #8 at max.	363.8
04 Jul 82	185	528	38	Leaf #9 at max.	495.0
04 Jul 82	185	528	38	Ear initiation	
07 Jul 82	188	570	41	Leaf #10 at max.	606.2
09 Jul 82	190	600	43	Leaf #11 at max.	747.6
12 Jul 82	193	636	46	Leaf #12 at max.	791.3
12 Jul 82	193	636	46	Leaves 1-3 dead	
14 Jul 82	195	665	48	Leaf #13 at max.	812.3
17 Jul 82	198	713	51	Leaf #14 at max.	764.0
19 Jul 82	200	745	53	Leaf #15 at max.	787.2
20 Jul 82	201	760	54	Leaf #16 at max.	742.6
22 Jul 82	203	791	56	Leaves 1-6 dead	
23 Jul 82	204	806	57	Leaf #17 at max.	614.7
27 Jul 82	208	864	61	Leaf #18 at max.	454.1
28 Jul 82	209	875	62	Leaf #19 at max.	337.5
30 Jul 82	211	899	64	Leaf #20 at max.	131.1
31 Jul 82+	212	911	65	Anthesis	
10 Aug 82	222	1051	75	Leaves 1-10 dead	
31 Aug 82	243	1329	96	Leaves 1-11 8 1/2 dead	
05 Sep 82+	248	1393	101	Beginning of dent	
08 Sep 82+	251	1427	104	Full dent (>50%)	
10 Sep 82	253	1450	106	Leaves 1-12 & 20 dead	
17 Sep 82	260	1514	113	Leaves 1-13 & 20 dead	
22 Sep 82	265	1544	118	Maturity	
24 Sep 82	267	1562	120	Leaves 1-15 & 18-20 dead	
06 Oct 82	279	1653	132	Harvest	

* Growing-Degree-Day

\+ Estimates

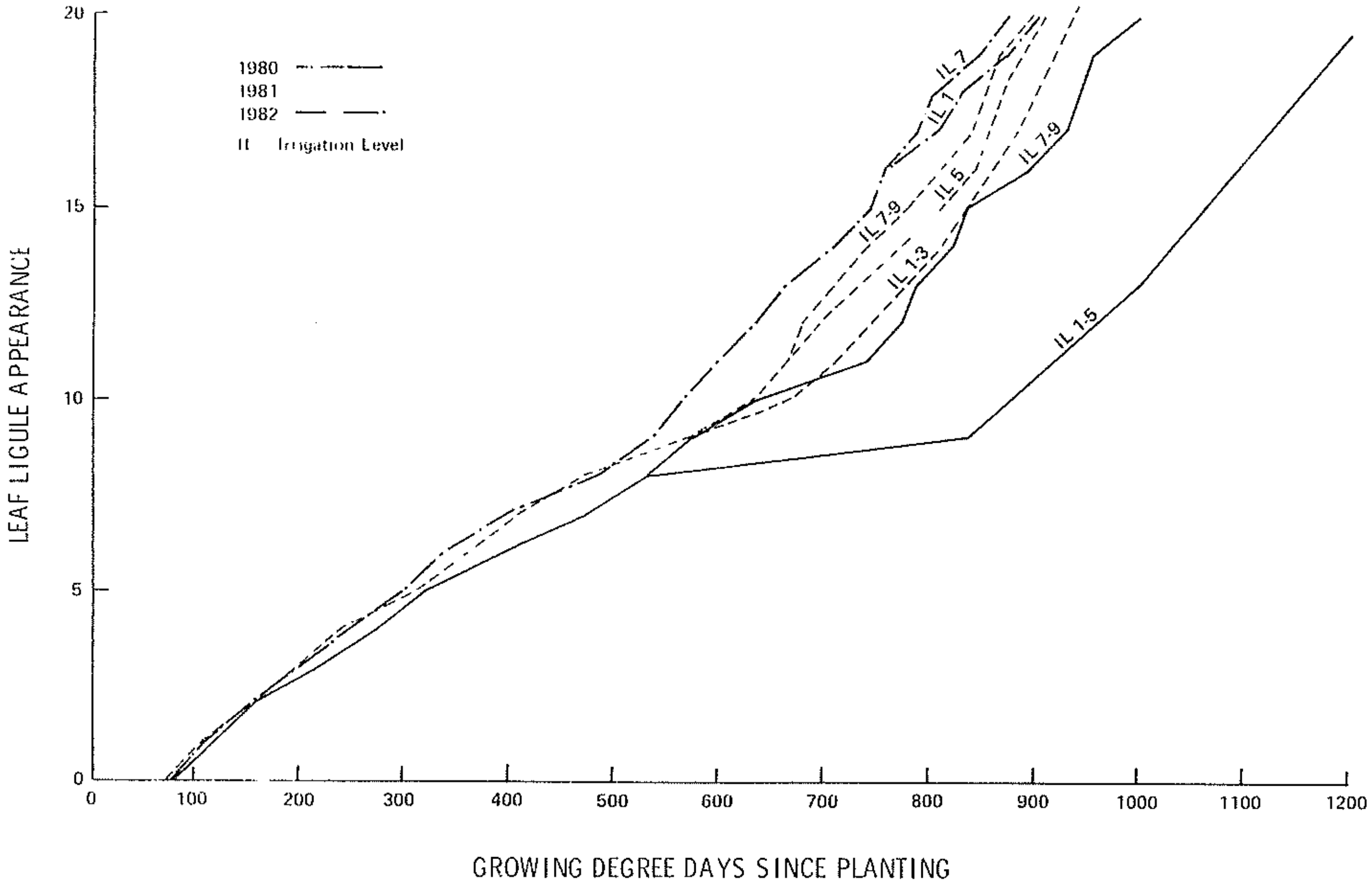

Figure 6. Rate of appearance of leaf ligules as a function of irrigation level for three growing seasons for Clovis corn, 1980, 1981, and 1982.

Modeling the Corn

In order to predict the response of corn to moisture stress conditions, the physiology of corn was modeled by Stapper and Arkin (1980). They developed a dynamic growth model of corn called CornF. The model has many functional relationships. One is a relationship found by Fischer (1979), which correlated final kernel number and dry matter at anthesis (see Appendix B). Figure 7 presents measurements of plant weight at anthesis versus the kernel numbers at harvest time. For the 1980 growing season, the coefficient of determination is 0.74. When the 1981 data are added to the data set, kernels per plant at harvest are related to plant weight by Equation 3:

$$\text{Kernels} = -36.8 + 4.62\ D_{\text{manth}} \tag{3}$$

$$r^2 = 0.64$$

The relationship used in the model by Stapper is very close to that derived at Clovis, New Mexico, for the 1980-1981 data. This indicates that the functional relationship in the model is correctly defined. However, in 1982, the corn had to be replanted and emerged so late that the relationship changed:

$$\text{Kernels} = -165 + 4.1\ D_{\text{manth}} \tag{4}$$

$$r^2 = 0.84$$

Under the conditions of late planting the number of kernels per plant under moisture stress decreased more than in a normal year, but as will be discussed later, the kernel size increased.

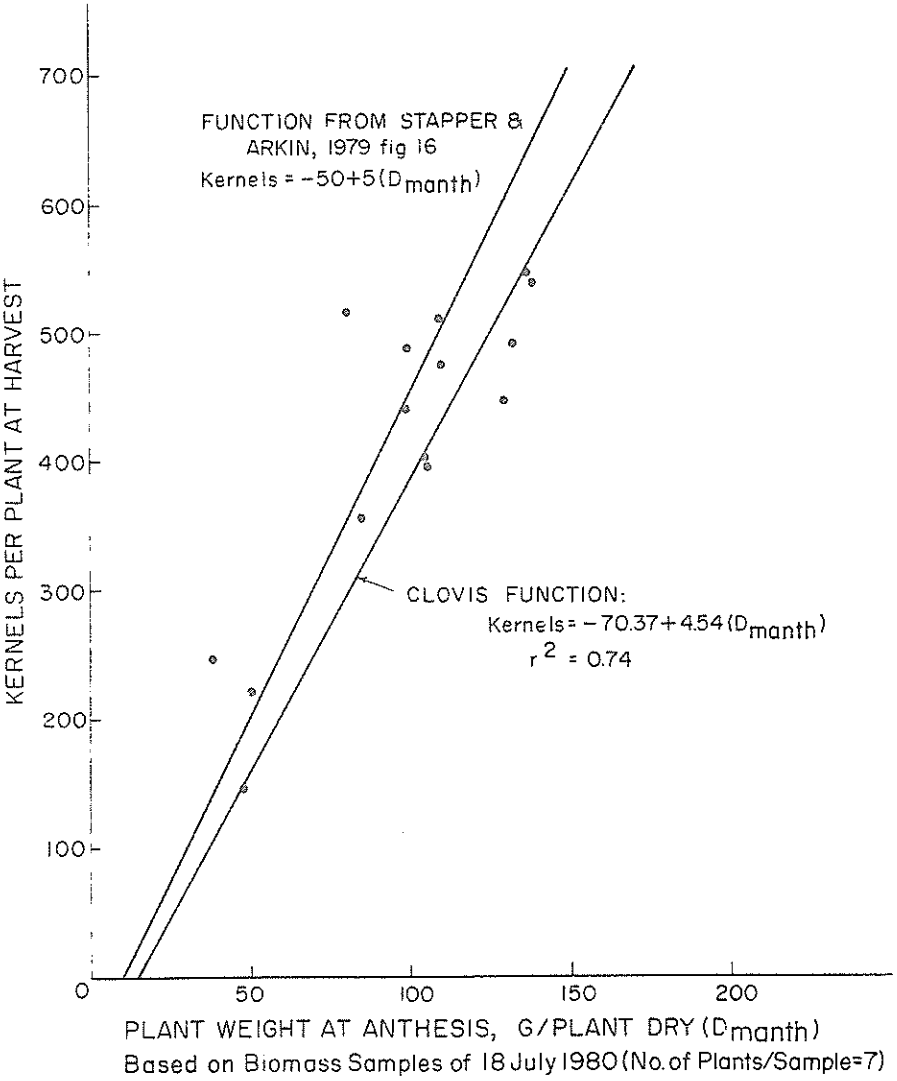

Figure 7. Kernel number per plant at harvest (KRNLS) as a function of above ground plant weight at anthesis.

Models, including the one by Stapper and Arkin (1980), normally include a physiological clock which is based on G rather than calendar days. Growing-degree-days account for the differences in heat units from year to year as they affect the physiological development of the crop.

Figure 8 presents the leaf ligule appearance at the line as a function of the accumulative G after planting. It took approximately 1000 G for anthesis to occur in 1980 and 900 G for anthesis to occur in 1981 and 1982.

The Physiological Development of Corn Under Moisture Stress Conditions

The model CornF originally was developed to simulate corn growth over a wide range of climatic conditions. The model was developed for corn growth when rainfall was not a limiting factor. The model does have a moisture stress parameter that reduces root growth, photosynthesis rates, transpiration rates, leaf senescence, and kernel number as soil moisture becomes limiting. Soil moisture stress was calculated based on the total root zone depth. The option to calculate soil moisture stress based on the top layer when it was higher than the total root zone soil moisture stress was deleted. Also, the coefficient in the Priestly and Taylor method (1972) of calculating potential evapotranspiration was adjusted to 1.86 to represent the climatic conditions at Clovis, New Mexico. The corn model CornF was run at four simulated irrigation levels representing average water applied at selected distances from the sprinkler-line-source (Appendix C).

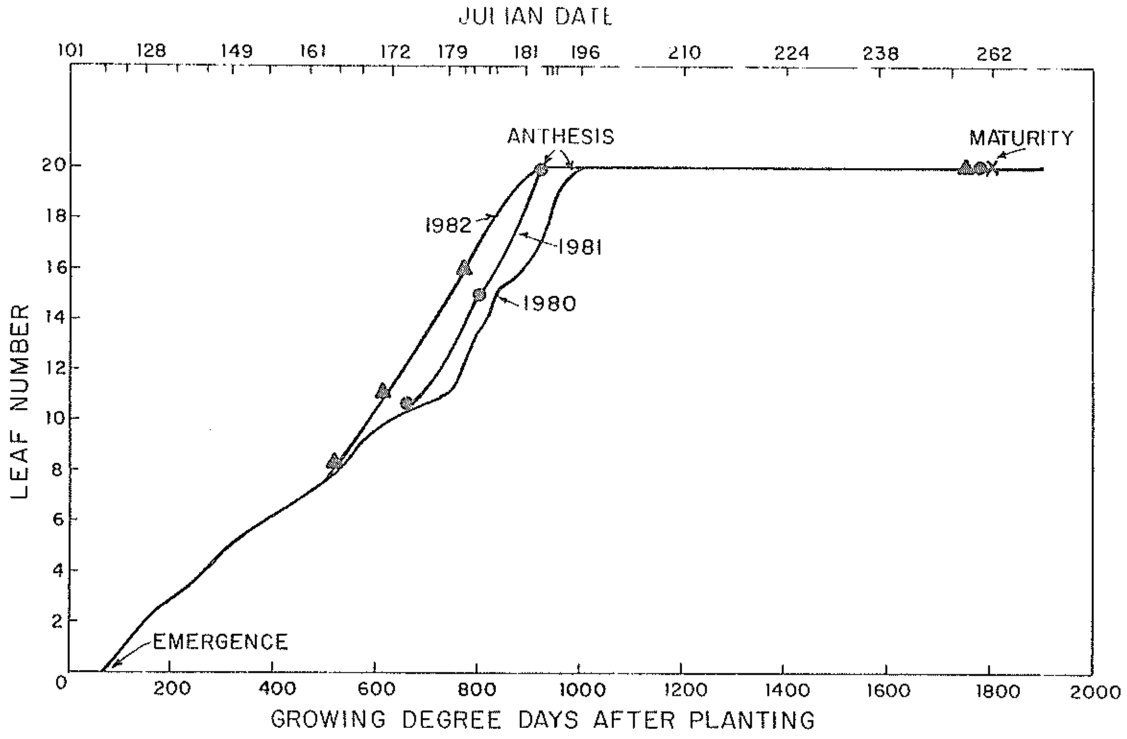

Figure 8. Leaf ligule appearance at the line as a function of accumulated growing-degree-days after planting.

The model CornF in its original form had no mechanism for decreasing the leaf growth rate of the plants or accounting for the time it takes for physiological development of the different stages to occur based on soil moisture stress. Also, the model does not account for reduction in leaf area due to hail damage. Moisture stress caused a decrease in the amount of plant material. Table 14 presents a comparison between the modeled and measured days for leaf appearance and leaf size. The comparison for leaf appearance and leaf size are for nonmoisture stress conditions at the sprinkler-line in 1980-1982 and for moisture stress at the edge of the field only in 1982. The model satisfactorily simulated physiological development of leaves under nonmoisture stress conditions. The model also estimates the timing of physiological events to be the same under different moisture stress conditions. This has been shown to be delayed when soil moisture is limited. Sufficient data were not available to modify the physiological clock to include the affect of soil moisture stress on physiological development. A comparison of observed (D_o) and modeled days (D_m) to maturity of a leaf ligule should result in a linear equation with an intercept of zero and a slope of one. The resulting equation using the 1980-1981 data located at the sprinkler-line is:

$$D_o = -0.68 + 1.01\ D_m \tag{5}$$

The coefficient of variation is 0.99.

In 1982, the corn plants were not delayed in their development rate at the edge of the field under moisture stress because high rainfall reduced moisture stress. However, the model predicted the appearance

Table 14. A comparison between measured and modeled leaf area.

LEAF AREA IN 1980 LOCATED AT THE SPRINKLER LINE

Measured			Modeled			
Leaf No.	Date Julian	Leaf Area cm^2	Date Julian	Leaf Area 1/	Leaf Area 2/ cm^2	Leaf Area 3/ cm^2
1	121	6.8	119	6.8	6.8	5.7
2	128	- *	125	17.9	1.8	1.0
3	138	- *	134	36.0	1.0	0.3
4	145	26.8	143	65.4	8.4	8.2
5	149	59.3	149	140.4	76.0	76.0
6	155	113.7	153	225.2	152.3	152.3
7	161	176.2	158	320.9	238.7	235.5
8	165	275.5	162	315.5	336.2	306.3
9	168	431.4	166	405.4	328.2	331.5
10	172	547.1	170	507.0	419.7	415.1
11	179	668.3	173	621.8	523.2	528.1
12	181	704.3	176	685.2	616.2	569.9
13	182	735.4	179	729.6	681.2	657.0
14	184	735.1	183	670.8	622.3	600.5
15	185	693.9	184	612.0	559.9	559.9
16	189	642.7	186	547.2	484.1	484.1
17	191	599.6	188	468.7	392.4	392.4
18	192	476.2	190	373.8	218.4	281.4
19	193	342.3	192	258.9	147.1	144.3
20	196	238.5	193	94.8	45.6	44.2

LEAF AREA IN 1981 LOCATED AT THE SPRINKLER LINE

Measured			Modeled		
Leaf No.	Date Julian	Leaf Area 4/ cm^2	Date Julian	Leaf Area 1/ cm^2	Leaf Area 5/ cm^2
1	118	7.8	117	7.8	7.8
2	123	14.2	121	26.5	20.5
3	129	21.3	127	41.2	41.2
4	135	39.9	137	75.0	59.9
5	144	77.4	144	151.3	93.1
6	148	129.8	151	237.4	144.0
7	154	183.6	156	334.8	279.2
8	159	214.7	160	325.5	296.8
9	166	317.6	164	416.4	294.9
10	171	365.2	168	519.2	151.1
11	173	460.8	172	635.4	359.6
12	174	479.9	175	693.5	481.7

1/ Leaf area with no hail damage.

2/ Reduced leaf area due to hail damage. Leaves 2 and 3 were set to 10 percent of the nonhail damaged size.

3/ Reduced leaf area due to soil moisture stress and hail damage.

4/ Hail damage occurred August 8, 1981, and prevented measurements of leaves 12 through 20. All leaves were completed in size before hail damage occurred.

5/ Reduced leaf area due to soil moisture stress.

(continued)

Table 14. (continued)

LEAF AREA IN 1982 LOCATED AT THE SPRINKLER LINE

Measured			Modeled			
Leaf No.	Date Julian	Leaf Area cm^2	Date Julian	Leaf Area 6/ cm^2	Leaf Area 7/ cm^2	Leaf Area 8/ cm^2
1	151	6.1	149	6.1	6.1	6.1
2	155	11.4	153	16.0	16.0	16.0
3	158	19.3	158	32.3	32.3	32.3
4	162	39.5	163	58.7	58.7	58.7
5	167	84.4	168	132.8	132.8	132.8
6	171	144.5	174	216.6	216.6	216.6
7	176	225.9	178	311.2	311.2	311.2
8	182	355.8	182	418.2	407.1	407.1
9	185	546.8	186	539.0	489.1	414.4
10	188	693.5	190	675.6	647.9	519.4
11	190	785.4	194	829.9	807.7	638.0
12	193	891.3	197	921.0	921.0	708.0
13	195	938.7	200	984.7	984.0	757.0
14	198	946.6	203	904.7	904.0	695.5
15	200	919.2	206	824.7	824.7	634.0
16	201	805.7	208	734.8	734.8	564.9
17	203	726.0	211	626.2	626.2	481.4
18	204	626.2	213	494.7	494.7	380.3
19	207	433.4	215	335.5	335.5	257.9
20	209	204.9	216	143.0	154.2	109.9
21	None	None	218	36.9	42.5	28.4

LEAF AREA IN 1982 LOCATED AT THE EDGE OF THE FIELD

Measured			Modeled			
Leaf No.	Date Julian	Leaf Area cm^2	Date Julian	Leaf Area 6/ cm^2	Leaf Area 7/ cm^2	Leaf Area 8/ cm^2
1	151	6.1	149	6.1	6.1	6.1
2	155	11.4	153	16.0	16.0	16.0
3	158	19.3	158	32.3	32.3	32.3
4	162	39.5	163	58.7	58.7	58.7
5	167	84.4	168	132.8	132.8	132.8
6	171	144.5	174	216.6	216.6	216.6
7	176	225.9	178	311.2	311.2	311.2
8	182	355.8	182	418.2	407.1	407.1
9	185	546.8	186	539.0	489.1	375.0
10	188	693.5	190	675.6	483.7	372.6
11	190	785.4	194	829.9	725.6	558.9
12	193	891.3	197	921.0	800.8	618.5
13	195	872.5	200	984.7	797.6	617.9
14	198	877.3	203	904.7	674.6	525.1
15	200	836.5	206	824.7	555.3	431.0
16	201	773.1	208	734.8	467.5	359.8
17	204	665.3	211	626.2	395.7	301.7
18	206	529.6	213	494.7	374.2	285.9
19	209	357.4	215	335.5	218.6	214.5
20	211	142.8	216	143.0	148.4	113.4
21	None	None	218	36.9	36.8	27.6

6/ Dlared set to 1.0, no moisture stress.

7/ Reduced leaf sizes due to soil moisture stress with density reduction factor (DLAR) set to 1.

8/ Before dlared modification, but excluding moisture stress reduction in leaf size. DLAR does not change leaf size until after leaf 7.

of the leaves later than measured in the field in 1982 due to the late planting. Equation 6 describes the 1982 relationship for irrigation levels located at the sprinkler-line and edge of the field.

$$D_o = 22.4 + 0.86\ D_m \qquad (6)$$

$$r_2 = 0.99$$

The model was modified to produce daily leaf growth as a function of soil moisture stress. In Figure 9, soil moisture stress is defined as the ratio between actual available soil water and potential available soil moisture in the root zone. The soil moisture stress function calculated a scaling factor (WATCO) varying from 0 to 1. Leaf growth in cm/day is reduced by this scaling factor. The reduction in daily leaf growth (RDLG) in cm is then portioned among the leaf (J) which is reduced by 50 percent of the RDLG and leaf J + 1 and leaf J + 2 which are each reduced 25 percent of the RDLG. At the time the primary leaf (J) is growing, leaves J + 1 and J + 2 also are growing.

The model also has been modified to decrease leaf size due to hail damage. Input data include the individual leaf number that was damaged by hail and the percentage of leaves remaining after the hail event. If the hail occurred after the end of leaf growth, then the date of the hail event and the percent of plant material remaining are specified as input.

A comparison can be made between measured leaf size and simulated leaf size. Leaf size was measured in 1980 and 1981 only at the line (Table 14). In 1982, leaf size was measured both at the line and on the edge of the field. Table 15 gives the linear relationship between the measured and modeled leaf area. When the model CornF was not modified

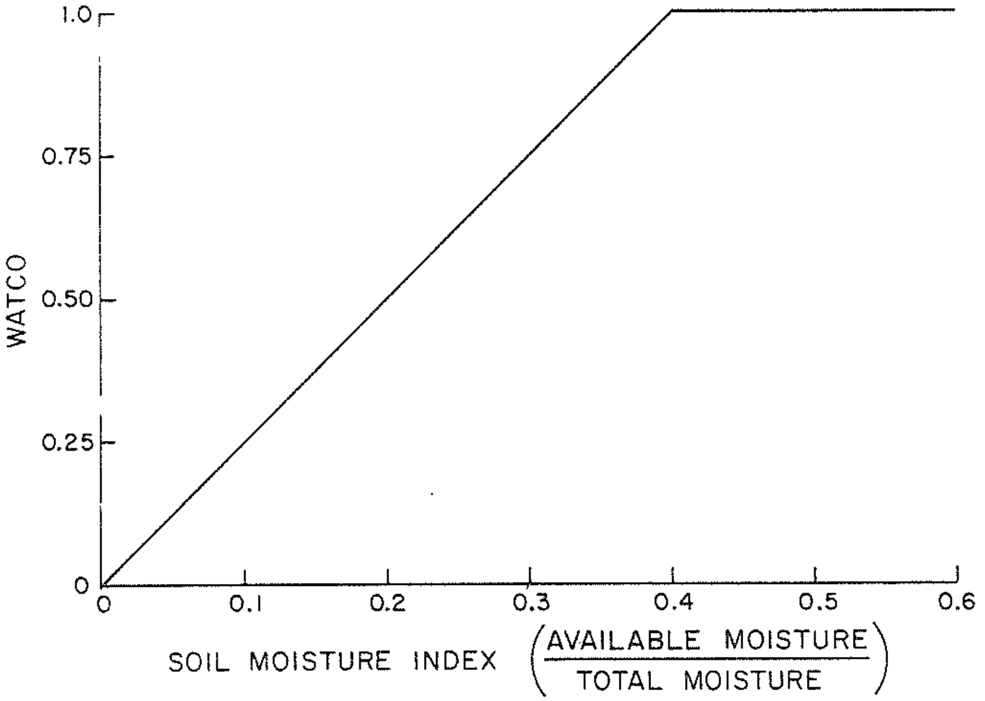

Figure 9. The relationship between the soil moisture index and WATCO, a scaling factor to reduce leaf size.

Table 15. The linear relationship between measured leaf area (L) and modeled leaf area (M).

Model Simulation Condition	Equation	Coefficient of Determination
	cm^2 cm^2	
	1980 Measured at the Sprinkler-Line	
-	$L = -17.9 + 1.11\ M$	0.91
H[1]	$L = 48.5 + 1.11\ M$	0.89
H + SM[2]	$L = 42.8 + 1.16\ M$	0.90
	1981 Measured at the Sprinkler-Line	
-	$L = -16.2 + 0.72\ M$	0.99
SM	$L = 5.03 + 1.00\ M$	0.78
	1982 Measured at the Sprinkler-Line	
D[3]	$L = -6.21 + 1.04\ M$	0.97
SM + D	$L = -5.66 + 1.04\ M$	0.97
SM	$L = -0.08 + 1.33\ M$	0.96
	1982 Measured at the Edge of Field	
D	$L = 21.82 + 0.99\ M$	0.98
SM + D	$L = -15.39 + 1.24\ M$	0.90
SM	$L = -25.50 + 1.57\ M$	0.84

[1] H represents model reduction to hail damage only.

[2] H + SM represents model reduction to hail plus soil moisture stress.

[3] D represents the plant density function DLAR set to 1.

for hail or soil moisture stress, the leaf size was modeled in 1980 on an average of 11 percent lower than the measured values. When hail damage was incorporated into the model (CornF Modified version I), the linear regression slope remained the same but the intercept changed. Again, the model underestimated the leaf area by 11 percent.

In 1981 at the sprinkler-line, where no soil moisture stress should have existed but did occur in our irrigation scheme according to the model, leaf size was overestimated by 28 percent. When the soil moisture reduction was incorporated into the model, the modeled and measured values had a slope of one. However, the coefficient of determination dropped from 0.99 to 0.78.

In 1982, a population density scaling factor DLAR ranging from 0 to 1 had to be adjusted to 1 due to the low density of planting. When this was incorporated into the model (CornF Modified version II), the model underestimated leaf size at the sprinkler-line by 4 percent. Also, when soil moisture stress was included in the model, it still underestimated leaf size by 4 percent. However, if the DLAR reduction factor was not adjusted from the calculated 0.6 and the soil moisture reduction factor was incorporated into the model, the model underestimated leaf size by 33 percent.

On the edge of the field, when the density reduction factor was incorporated, the model had a 0.99 slope compared to the measured value. When the soil moisture stress factor was added to the model, the leaf size was underestimated by 24 percent. If the model had only soil moisture stress in it and the density factor was not incorporated into the model, the model underestimated leaf size by 57 percent. Table 15 shows that when soil moisture is incorporated into the model, the model understimates leaf size under moisture stress conditions; under non-moisture stress conditions at the sprinkler-line, the model in one year, underestimated leaf size and in the next year, overestimated leaf size. Therefore, the functional relationship used to reduce leaf size may be too large. However, leaf-area-index (the ratio of the total leaf area to the unit ground area) will be drastically overestimated by the model without the reduction in the leaf size due to soil moisture stress and hail damage (Table 16). When the leaf area reduction factor is included the maximum modeled leaf area index (L_{AIm}) as presented in Table 16, is related to the measured maximum L_{AI} by Equation 7.

$$L_{AI} = 0.41 + 1.07\ L_{AIm} \qquad (7)$$

$$r^2 = 0.88$$

Table 17 presents a comparison between the measured and modeled grain weight per ear produced over the growing season for selected irrigation levels. The model simulates within 2 percent for 1980, the final grain production under a nonmoisture stress condition, which was the original condition under which the model was developed. As moisture stress occurs, the model overestimates grain yield as shown in Table 18. This overestimation is due to the fact that the model, as stated earlier, was unable to simulate reduction in leaf growth and consequently, plant photosynthetic activity under moisture stress conditions. When leaf size reduction due to hail and soil moisture stress were incorporated into the model in 1980 and 1981, the model CornF I still overestimated

Table 16. Change in leaf area/plant and leaf area index during the growing period (measured and modeled) at four irrigation levels.

(Julian Date) Date	1980														
	(113) 4/22			(150) 5/29			(168) 6/16			(200) 7/18			(255) 9/11		
	Leaf Area/Plant cm^2 (Leaf-Area-Index)			Leaf Area/Plant cm^2 (Leaf-Area-Index)			Leaf Area/Plant cm^2 (Leaf-Area-Index)			Leaf Area/Plant cm^2 (Leaf-Area-Index)			Leaf Area/Plant cm^2 (Leaf-Area-Index)		
Simulated Irrig. Level	Meas.	CornF	Modified CornF 1	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I
1	0 (0)	0 (0)	0 (0)	124 (0.07)	585 (0.34)	317 (0.19)	1280 (0.75)	2492 (1.46)	1640 (0.96)	2862 (1.67)	6374 (3.74)	3583 (1.52)	1432 (0.84)	0 (0)	528 (0.55)
3	0 (0)	0 (0)	0 (0)	124 (0.07)	585 (0.34)	317 (0.19)	1455 (0.85)	2492 (1.46)	1773 (1.04)	3828 (2.23)	6374 (3.74)	3094 (1.82)	2300 (1.34)	178 (0.10)	0 (0)
5	0 (0)	0 (0)	0 (0)	124 (0.07)	585 (0.34)	317 (0.19)	1798 (1.05)	2492 (1.46)	1979 (1.16)	5669 (3.31)	6374 (3.74)	4672 (2.76)	3949 (2.30)	437 (0.26)	260 (0.15)
9	0 (0)	0 (0)	0 (0)	124 (0.07)	585 (0.34)	317 (0.19)	1758 (1.03)	2492 (1.46)	2259 (1.16)	6102 (3.56)	6374 (3.74)	5410 (3.18)	4136 (2.41)	1279 (0.75)	957 (0.56)

(Julian Date) Date	1981									
	(114) 4/24		(141) 5/21		(162) 6/11		(183) 7/02		(236) 8/24	
	Leaf Area/Plant cm^2 (Leaf-Area-Index)		Leaf Area/Plant cm^2 (Leaf-Area-Index)		Leaf Area/Plant cm^2 (Leaf-Area-Index)		Leaf Area/Plant cm^2 (Leaf-Area-Index)		Leaf Area/Plant cm^2 (Leaf-Area-Index)	
Irrig. Level	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I
1	0 (0)	0 (0)	292 (0.18)	363.7 (0.22)	1601 (0.96)	1577 (0.95)	4000 (2.40)	3323 (1.99)	3138 (1.88)	2394 (1.44)
3	0 (0)	0 (0)	292 (0.18)	363.7 (0.22)	1601 (0.96)	1577 (0.95)	4875 (2.93)	3563 (2.14)	3095 (1.86)	2518 (1.51)
5	0 (0)	0 (0)	292 (0.18)	363.7 (0.22)	1601 (0.96)	1577 (0.95)	5863 (3.52)	4182 (2.51)	3504 (2.10)	2905 (1.74)
7	0 (0)	0 (0)	292 (0.18)	363.7 (0.22)	1601 (0.96)	1577 (0.95)	5805 (3.48)	4512 (2.71)	3126 (1.88)	3153 (1.89)

(continued)

Table 16. (continued)

1982

(Julian Date) Date	(147) 5/27 Leaf Area/Plant cm^2 (Leaf Area Index)			(165) 6/14 Leaf Area/Plant cm^2 (Leaf Area Index)			(173) 6/22 Leaf Area/Plant cm^2 (Leaf Area Index)			(203) 7/22 Leaf Area/Plant cm^2 (Leaf Area Index)			(222) 8/10 Leaf Area/Plant cm^2 (Leaf Area Index)		
Irrig. Level	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II
1	0 (0)	0 (0)	0 (0)	237 (0.11)	326 (0.16)	326 (0.16)	932 (0.44)	753 (0.36)	753 (0.36)	6859 (3.27)	4997 (2.38)	5997 (2.85)	9767 (4.66)	5635 (2.69)	6922 (3.30)
3	0 (0)	0 (0)	0 (0)	237 (0.11)	326 (0.16)	326 (0.16)	932 (0.44)	753 (0.36)	753 (0.36)	8393 (4.00)	5341 (2.55)	6443 (3.07)	8306 (3.96)	6134 (2.92)	7595 (3.62)
5	0 (0)	0 (0)	0 (0)	237 (0.11)	326 (0.16)	326 (0.16)	932 (0.44)	753 (0.36)	753 (0.36)	7846 (3.74)	5723 (2.73)	6946 (3.31)	9259 (4.42)	6842 (3.26)	8510 (4.06)
7	0 (0)	0 (0)	0 (0)	237 (0.11)	326 (0.16)	326 (0.16)	932 (0.44)	753 (0.36)	753 (0.36)	8601 (4.10)	5740 (2.74)	6971 (3.32)	10092 (4.81)	6958 (3.32)	8662 (4.13)
Mean	0	0	0	237			932			7924			9350		
LSD				N.A.			N.A.			1393			1478		

(Julian Date) Date	(242) 8/30 Leaf Area/Plant cm^2 (Leaf Area Index)			(253) 9/10 Leaf Area/Plant cm^2 (Leaf Area Index)			(260) 9/17 Leaf Area/Plant cm^2 (Leaf Area Index)			(267) 9/24 Leaf Area/Plant cm^2 (Leaf Area Index)			(279) 10/6 Leaf Area/Plant cm^2 (Leaf Area Index)		
Irrig. Level	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II
1	7976 (3.80)	4541 (2.17)	5714 (2.72)	4612 (2.20)	4167 (1.99)	5231 (2.49)	3357 (1.60)	3610 (1.72)	4005 (2.15)	594 (0.28)	3610 (1.72)	4505 (2.15)	0	2991 (1.43)	3704 (1.77)
3	9197 (4.39)	5041 (2.40)	6837 (3.05)	7559 (3.61)	4578 (2.18)	5785 (2.76)	4328 (2.06)	3974 (1.89)	5000 (2.38)	1488 (0.71)	3974 (1.89)	5000 (2.38)	0	3287 (1.57)	3244 (1.55)
5	10174 (4.85)	5749 (2.74)	7303 (3.48)	8728 (4.16)	5252 (2.50)	6655 (3.17)	6716 (3.20)	4631 (2.21)	5847 (2.79)	4849 (2.31)	4631 (2.21)	5847 (2.79)	0	3169 (1.51)	3946 (1.88)
7	10410 (4.97)	5865 (2.80)	7454 (3.55)	10308 (4.92)	5368 (2.56)	6807 (3.25)	9228 (4.40)	5368 (2.56)	6807 (3.25)	7590 (3.62)	4747 (2.62)	5999 (2.86)	0	4039 (1.93)	5078 (2.42)
Mean	9439			7801			5907			3630					
LSD	1348			1945			2903			906					

Table 17. Change in corn grain weight per ear (dry grams) during the growing period at four irrigation levels.

Growing Season 1980

Growing Degree Days	1065			1250			1400			1500			1750			1930			1940
(Julian Date) Date	(201) 7/19			(213) 7/31			(224) 8/11			(231) 8/18			(252) 9/08			(274) 9/30			(278) 10/4
Simulated Irrig. Level	Meas. 1/	CornF	Modified CornF I 2/	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas. 3/
1	0	0	0	1.2	2.8	2.5	2.4	8.6	4.5	3.9	11.9	6.9	1.5	19.3	9.3	4.0	19.3	9.3	3.9
3	0	0	0	2.3	9.0	5.0	12.7	26.5	10.8	18.9	36.1	14.8	18.1	58.3	21.9	10.9	58.3	21.9	13.3
5	0	0	0	9.9	28.8	20.8	33.8	73.4	53.0	96.0	97.9	72.2	125.4	147.6	101.6	105.2	147.6	101.6	76.2
9	0	0	0	10.0	32.9	27.0	60.8	78.3	63.7	116.0	102.9	83.3	161.1	159.5	126.6	155.7	159.6	126.6	137.2

1/ Based on biomass samples; average of 7 plants/1.2m^2.
2/ Modified version to include hail and soil moisture effect on leaf size.
3/ Based on machine-harvesting.

Growing Season 1982

Growing Degree Days	956			1315			1450			1482			1514			1562					
(Julian Date) Date	(215) 8/01			(242) 8/30			(253) 9/10			(256) 9/13			(260) 9/17			(267) 9/24			At Modeled Maturity		
Simulated Irrig. Level	Meas.	CornF	Modified CornF	Meas.	Modified CornF I	Modified CornF II 1/	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II
1	0	0	0	67.8	21.3	23.8	115.9	31.0	37.1	122.8	31.5	38.2	133.6	31.5	38.4	123.0	31.5	38.4		31.5	38.4
3	0	0	0	76.7	29.0	31.1	133.3	47.2	56.0	147.4	49.5	59.2	174.5	50.9	61.3	131.0	53.2	65.1		53.9	73.1
5	0	0	0	85.7	47.2	48.9	155.9	85.4	96.8	138.5	91.6	104.3	163.2	96.2	110.2	165.8	102.9	118.9		114.8	134.9
7	0	0	0	105.6	56.6	56.6	168.1	105.8	115.8	133.5	116.9	129.0	176.8	126.3	140.9	203.8	138.3	156.4		158.2	182.1
Mean	0	0	0	83.9			143.3			135.5			162.1			155.9					
LSD	-	-	-	22.7			18.7			33.0			41.9			30.2					

1/ Modified CornFI - Diared set to 1 throughout the program and includes soil moisture stress. There was no hail damage in 1982.

Table 18. Comparisons between observed and modeled seasonal grain yield, and total dry matter of corn growth at four irrigation levels.

	Grain Yield kg/ha				Total Dry Matter Produced kg/ha		
Irrigation Level	Meas.[1/]	Meas.[2/]	CornF	Modified CornF I	Meas.	CornF	Modified CornF I
1980							
Simulated							
1	279	274	1340	645	3713	5985	3820
3	755	924	4035	1519	5519	11311	6016
5	7311	5290	10226	7040	15469	22406	15948
9	10816	9533	11052	8768	20242	25356	19500
1981							
1		5320		6734	11950		11417
3		6273		7263	11130		12163
5		7367		8140	13060		13797
7		7763		8618	12510		14683

[1/] Hand-harvested results.

[2/] Machine-harvested results.

			Modified CornF I	Modified CornF II		Modified CornF I	Modified CornF II
1982							
1	6940[1/]	5427[2/]	1771	2163	13764	8393	9351
3	7391	7197	3030	4114	14512	10529	12265
5	9354	7987	6457	7588	18336	16064	18025
7	11498	8866	8901	10246	21606	18677	20862

[1/] Based on final biomass samples 09/24/82.

[2/] Based on machine-harvest.

grain yield under moisture stress but the predictability of the model was improved. The regression equation comparing measured to modeled grain yield is:

$$G_r = -688 + 0.99\ G_{rm} \tag{8}$$

where

G_{rm} = Grain modeled in kg/ha

G_r = Grain measured in kg/ha

The coefficient of determination is 0.93.

In 1982, the density population was low and the model underestimated grain per cob and total grain yield even with the DLAR set to 1. The underestimation of grain yield under moisture stress was due to a reduction in the grain size and number of kernels predicted by the model. This reduction did not occur in the field (Table 19). The model was developed and tested under normal planting density and appears to fail under low planting density. Under moisture stress conditions, the relationship between measured and modeled grain yield in 1982 is:

$$G_{mm} = 5022 + 0.39\ G_m \tag{9}$$

$$r^2 = 0.92$$

Table 18 also presents the dry matter measured and predicted values during the growing season. The model in 1980-1981 simulated total

Table 19. Clovis corn variation in number of kernels per plant (ear) and kernel weight at different irrigation levels for three different years, at harvest.

		Measured			Modeled		
Year	Irrigation Level	Dry Grain Weight Per Ear	Mean Number Kernels Per Ear	Dry Weight Per Kernels	Dry Grain Weight Per Ear	Number Kernels Per Ear	Dry Weight Per Kernels
		g		g	g		g
1980	1	4.0	25	0.10	9.3	53	0.18
	3	10.9	126	0.26	21.9	108	0.20
	5	105.2	423	0.29	101.6	449	0.23
	9	155.7	523	0.31	126.6	686	0.18
1981	1	74.9	352	0.21	95.1	373	0.25
	3	88.4	386	0.23	102.6	408	0.25
	5	103.8	453	0.23	115.0	523	0.22
	7	109.3	477	0.23	140.2	639	0.22
	9	103.6	452	0.23	101.4	559	0.18
1982	1	123.0	399	0.31	38.4	316	0.12
	3	131.0	410	0.32	73.1	412	0.18
	5	165.8	449	0.37	134.9	649	0.21
	7	203.8	544	0.37	182.1	750	0.24

biomass better than grain yield as shown by Equation 10.

$$Y_B = -503 + 1.00\ Y_{BM} \qquad (10)$$

$r^2 = 0.97$

Y_B = yield measured biomass kg/ha

Y_{BM} = yield modeled biomass kg/ha

In 1982, total biomass was underestimated by the model. The comparison between the modeled and measured biomass is described by Equation 11.

$$Y_B = 6811 + 0.68\ Y_{Bm} \qquad (11)$$

$r_2 = 0.93$

When a comparison is made between measured and modeled biomass per plant and accumulated over time (Table 20), the 1980-1981 years can be described by Equation 12.

$$Y_{BT} = -10.1 + 6.04 Y_{BTm} \qquad (12)$$

$r_2 = 0.96$

Y_{BT} = measured biomass per plant (g) over time

Y_{BTm} = model biomass per plant (g) over time

Due to the low density in the field, the model underestimates biomass in 1982 as represented by Equation 13:

$$Y_{BT} = 3.8 + 1.18\ Y_{BTm} \qquad (13)$$

$r^2 = 0.96$

Table 20. Change in the dry weight/plant (grams) during the growing period: measured vs. modeled.

(Julian Date)	1980														
Date	(113) 4/22			(150) 5/29			(168) 6/16			(200) 7/18			(252) 9/09		
Simulated Irrig. Level	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I	Meas.	CornF	Modified CornF I
1	0	0	0	0.7	14.3	4.1	8.4	39.7	23.8	37.0	73.5	53.9	62.7	102.0	65.1
3	0	0	0	0.7	14.3	4.1	9.6	43.0	25.8	56.7	115.6	74.0	94.6	192.7	102.5
5	0	0	0	0.7	14.3	4.1	11.9	52.6	30.8	101.1	195.5	142.9	285.5	381.0	271.9
9	0	0	0	0.7	14.3	4.1	11.6	55.8	31.1	122.6	231.4	173.4	336.7	430.9	331.5

(Julian Date)	1981									
Date	(114) 4/24		(141) 5/21		(162) 6/11		(183) 7/2		(246) 8/24	
Simulated Irrig. Level	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I	Meas.	Modified CornF I
1	0		1.0	6.0	13.3	26.5	28.3	58.0	199.2	156.2
3	0		1.0	6.0	13.3	26.5	35.7	63.4	185.5	167.2
5	0	0	1.0	6.0	13.3	26.5	43.2	77.3	217.7	192.0
7	0	0	1.0	6.0	13.3	26.5	45.5	84.3	208.5	205.1

(Julian Date)	1982														
Date	(146) 05/26			(165) 06/14			(173) 06/22			(203) 07/22			(222) 08/10		
Simulated Irrig. Level	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II
1	0	0	0	1.0	4.0	4.0	5.3	11.0	11.0	92.4	89.7	94.5	220.4	145.8	157.6
3	0	0	0	1.0	4.0	4.0	5.3	11.0	11.0	109.2	97.4	103.4	174.3	165.3	179.3
5	0	0	0	1.0	4.0	4.0	5.3	11.0	11.0	108.0	106.9	113.9	235.1	199.0	214.8
7	0	0	0	1.0	4.0	4.0	5.3	11.0	11.0	110.5	107.3	114.3	257.1	204.0	219.7
Mean	0	0	0	1.0			5.3			105.2			221.7		
LSD	--	--	--	----			----			22.6			31.8		

(Julian Date)	1982														
Date	(246) 08/30			(253) 09/10			(260) 09/17			(267) 09/24				Modeled at Maturity	
Simulated Irrig. Level	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II	Meas.	Modified CornF I	Modified CornF II
1	273.9	172.2	189.8	292.8	175.5	194.8	319.1	176.0	196.1	288.7	176.0	196.1	----	176.0	196.1
3	300.6	204.6	227.2	346.7	214.2	239.5	369.6	217.9	244.8	304.4	220.2	248.5	----	220.9	257.3
5	336.9	283.5	311.2	395.7	306.6	338.4	396.0	317.4	351.9	384.6	324.1	360.6	----	337.0	378.1
7	361.1	308.2	335.4	444.6	337.6	368.4	436.4	358.1	393.5	453.2	370.1	408.9	----	391.8	437.6
Mean	318.2			369.9			380.3			357.7					
LSD	53.1			72.4			96.5			N/A					

SUMMARY AND CONCLUSIONS

A linear water-production function was derived for corn using a sprinkler-line-source system. Because of the residual nitrogen in the soil, there was no response to the nitrogen treatments imposed upon the individual plots in 1980. In 1981 and 1982, the nitrogen stress reduced yield but did not affect the water-production function relationships These findings indicate that nitrogen stress can cause a reduction in plant size and grain yield. However, nitrogen stress also reduces evapotranspiration, which leaves the water-production unchanged. Data were collected on the physiological developments of the corn plants under different irrigation regimes, and the results were tested against a physiological based model. The model does simulate corn production under nonmoisture stress conditions. It overestimated production with increased discrepancy between predicted and simulated values as moisture stress increased. The model was modified to account for change in leaf area under moisture stress conditions. The modified form of the model improved the prediction of grain yield and biomass production, but still the model overestimated production under soil moisture stress conditions.

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APPENDIX A

Table A1. Amount of applied irrigation water to each corn plot, for 1980.

(Julian Date)		160	175	183	191	195	199	210	219	237	246	
Date		6/09	6/24	7/02	7/10	7/14	7/18	7/29	8/07	8/25	9/03	
Station No.		Applied Irrigation Water										Total Amount Water Applied
		(cm)										(cm)
1		0.00	0.00	1.68	0.00	0.08	0.00	0.00	0.00	0.05	0.00	1.80
2		0.05	0.84	3.00	0.13	0.61	0.00	0.20	0.08	1.96	0.38	7.24
3		0.20	2.46	4.60	0.76	1.73	0.61	1.09	0.91	2.92	1.60	16.89
4		1.17	4.45	5.87	1.96	2.54	2.29	3.00	3.00	2.97	2.90	30.12
5		2.74	5.66	6.88	3.15	3.12	4.67	5.46	4.90	2.97	3.78	43.36
6	Plot 1	3.38	6.88	7.95	4.60	4.01	7.65	7.16	6.91	4.75	4.32	57.61
7		7.95	7.11	9.35	5.00	4.52	8.74	7.62	7.42	4.45	4.52	66.67
8		8.81	7.90	9.50	5.00	4.57	9.25	6.91	8.20	4.80	4.45	69.39
9		8.59	8.28	8.71	4.65	4.47	8.51	7.11	7.11	4.52	4.32	66.27
10		7.52	8.08	6.17	4.01	4.01	7.62	6.88	6.45	4.27	4.01	59.03
11		6.76	6.02	3.40	3.84	3.25	6.88	6.32	6.12	3.18	4.32	50.09
12		4.39	3.51	1.42	3.20	2.64	6.25	5.13	5.28	2.79	3.40	38.02
13		3.00	1.30	0.41	2.44	2.29	4.80	3.02	3.40	2.62	1.91	25.17
14		1.50	0.23	0.00	1.75	1.80	2.87	1.30	1.68	1.68	0.56	13.36
15		0.33	0.00	0.00	0.84	0.61	1.02	0.00	0.18	0.23	0.00	3.20
1		0.00	0.03	2.59	0.05	0.23	0.00	0.00	0.00	1.75	0.00	4.65
2		0.05	1.55	4.01	0.28	0.89	0.05	0.38	0.13	2.87	0.56	10.77
3		0.64	3.91	6.12	1.35	2.13	0.97	1.47	1.27	3.40	2.03	23.29
4		2.64	5.49	7.67	2.46	2.77	2.77	3.15	3.33	4.04	3.28	37.59
5		4.88	6.15	9.91	4.11	3.84	5.92	6.10	5.99	6.27	4.78	57.94
6	Plot 2	8.20	7.29	10.44	5.66	5.05	8.36	7.92	8.03	6.99	5.61	73.56
7		5.69	6.45	10.74	5.66	5.44	8.94	8.33	8.38	6.27	5.38	71.30
8		7.59	7.42	10.67	5.61	5.64	9.25	7.98	8.46	6.93	5.36	74.90
9		8.05	6.93	8.59	4.62	5.23	8.43	7.49	8.13	8.59	5.26	71.32
10		7.44	6.25	4.85	4.50	4.47	7.72	6.68	7.47	7.49	5.33	62.20
11		5.41	3.76	1.93	3.84	3.40	7.04	5.99	6.38	4.32	4.52	46.58
12		3.71	1.45	0.53	3.07	2.79	5.99	4.24	4.67	3.53	3.20	33.20
13		1.96	0.05	0.00	2.16	2.34	3.71	2.34	2.64	1.55	1.52	18.26
14		0.74	0.00	0.00	1.45	1.32	2.03	0.79	1.17	0.00	0.33	7.82
15		0.13	0.00	0.00	0.74	0.25	0.46	0.00	0.10	0.00	0.00	1.68

(continued)

Table A1. (continued)

(Julian Date)		160	175	183	191	195	199	210	219	237	246	
Date		6/09	6/24	7/02	7/10	7/14	7/18	7/29	8/07	8/25	9/03	
Station No.		Applied Irrigation Water										Total Amount Water Applied
							(cm)					(cm)
1		0.08	0.00	0.00	0.69	0.13	0.46	0.00	0.00	0.00	0.00	1.35
2		0.84	0.00	0.00	1.68	1.09	2.18	0.64	0.94	0.00	0.15	7.52
3		1.98	0.30	0.00	2.46	2.03	3.89	2.29	2.57	1.30	1.42	18.24
4		3.56	1.65	0.53	3.30	3.02	5.16	4.19	4.39	4.70	3.15	33.65
5		5.41	3.84	1.98	3.94	3.81	6.45	5.46	5.99	4.62	4.42	45.92
6	Plot	5.79	6.53	4.88	4.39	4.11	7.42	6.99	6.83	3.94	5.46	56.34
7	3	8.28	7.87	8.38	4.75	4.55	7.44	6.83	7.59	4.01	5.84	65.56
8		8.00	8.15	10.16	5.66	8.33	8.59	8.03	8.43	7.85	6.43	79.63
9		9.78	7.57	10.36	5.44	5.36	9.25	7.77	8.05	5.16	5.33	74.07
10		7.95	7.19	9.91	5.13	4.70	8.46	7.42	8.20	3.07	5.79	67.82
11		5.46	6.60	8.81	3.94	3.91	6.38	6.12	6.22	2.21	5.18	54.84
12		2.54	4.62	7.37	2.49	2.82	3.15	3.71	3.63	2.84	3.53	36.70
13		0.71	3.40	5.66	1.32	1.88	1.30	1.91	3.00	4.11	2.21	25.50
14		0.05	1.70	4.19	0.53	1.02	0.53	0.48	0.20	4.01	0.66	13.39
15		0.00	0.00	2.11	0.00	0.15	0.00	0.00	0.00	0.58	0.00	2.84
1		0.10	0.00	0.00	0.51	0.25	0.79	0.10	0.25	0.10	0.00	2.11
2		0.94	0.00	0.00	0.81	1.42	2.39	1.04	1.37	1.40	0.46	9.83
3		2.54	0.74	0.38	1.22	2.74	4.37	2.92	3.28	3.33	2.21	23.72
4		4.27	3.07	1.40	1.45	3.53	6.15	4.62	4.90	3.71	3.68	36.78
5		1.88	1.09	3.81	1.63	4.34	7.65	6.58	6.45	3.12	4.65	41.20
6	Plot	8.51	8.71	7.72	1.73	5.08	8.33	6.96	7.52	3.40	4.88	62.84
7	4	8.28	7.87	10.06	1.75	5.23	8.48	7.04	8.51	5.49	4.80	67.51
8		7.90	7.87	10.97	2.08	6.96	10.01	7.62	9.68	7.47	5.51	76.07
9		7.85	7.29	10.87	2.11	5.51	10.01	7.37	8.33	4.14	5.38	68.86
10		7.57	7.47	10.03	1.73	5.00	8.59	8.03	8.20	2.84	5.64	65.10
11		3.89	6.55	8.64	1.30	4.04	4.80	5.49	5.41	2.77	4.57	47.45
12		1.02	4.47	6.93	0.64	2.59	1.96	2.72	2.29	3.89	3.00	29.49
13		0.13	2.36	5.23	0.18	1.47	0.28	0.84	0.43	3.35	1.32	15.60
14		0.00	0.33	3.07	0.00	0.36	0.00	0.05	0.00	1.24	0.10	5.16
15		0.00	0.00	1.40	0.00	0.08	0.00	0.00	0.00	0.05	0.00	1.52

Table A2. Amount of applied irrigation water to each corn plot, for 1981.

		Julian Date		
		170	208	
		Date		
		6/19	7/31	
Station No.		Applied Irrigation Water		Total Amount Water Applied
		cm		cm
1		0.64	1.78	2.42
2		2.02	2.79	4.81
3		3.69	2.96	6.65
4		5.10	4.69	9.79
5		5.31	6.48	11.79
6	Plot 1	6.69	7.24	13.93
7		7.37	7.47	14.84
8		7.43	6.60	14.03
9		6.42	6.11	12.53
10		5.15	5.11	10.26
11		3.39	3.05	6.44
12		1.83	1.35	3.18
13		0.28	0.54	0.82
14		0.00	0.05	0.05
15		0.00	0.04	0.04
1		0.46	2.09	2.55
2		1.67	3.04	4.71
3		2.76	3.52	6.28
4		4.11	4.16	8.27
5		5.18	5.28	10.41
6	Plot 2	6.44	5.86	12.30
7		7.50	7.39	14.89
8		7.55	7.15	14.70
9		4.50	6.60	11.10
10		5.55	3.86	9.41
11		3.90	2.01	5.91
12		1.64	0.82	2.46
13		0.27	0.09	0.36
14		0.00	0.00	0.00
15		0.00	0.00	0.00

(continued)

Table A2. (Continued)

		Julian Date		
		170	208	
		Date		
		6/19	7/31	
Station No.		Applied Irrigation Water		Total Amount Water Applied
		cm		cm
1		0.09	1.67	1.76
2		0.90	2.43	3.33
3		2.47	3.23	5.70
4		4.24	3.58	7.82
5		5.33	7.10	12.43
6	Plot 3	6.43	7.24	13.67
7		6.82	9.44	16.26
8		7.95	8.23	16.18
9		7.90	7.49	15.39
10		6.22	5.12	11.34
11		3.39	2.42	5.81
12		0.92	0.80	1.72
13		0.06	0.20	0.26
14		0.00	0.00	0.00
15		0.00	0.00	0.00
1		0.20	2.04	2.24
2		1.09	2.56	3.65
3		2.81	3.71	6.52
4		4.21	4.30	8.51
5		5.37	5.06	10.43
6	Plot 4	6.37	7.47	13.84
7		6.94	7.13	14.07
8		7.86	8.70	16.56
9		6.66	8.18	14.84
10		5.01	5.37	10.38
11		3.02	3.25	6.27
12		1.05	1.48	2.53
13		0.03	0.62	0.65
14		0.00	0.05	0.05
15		0.00	0.00	0.00

Table A3. Amount of applied irrigation water to each corn plot, for 1982. Plot number one is fertilized, plot number two is unfertilized.

		Date				
		7/06	7/26	8/12	9/01	
Station No.		Applied Irrigation Water				Total Amount Water Applied
		cm				cm
1	Plot 1	0.00	0.00	0.00	0.76	0.76
2		0.46	0.28	0.13	1.65	2.52
3		1.35	0.91	0.69	2.74	5.69
4		2.39	1.91	1.98	4.01	10.29
5		3.51	3.61	3.81	5.66	16.59
6		5.05	5.05	5.59	6.17	21.86
7		5.94	5.31	5.23	6.55	23.03
8		6.25	6.10	6.12	6.50	24.97
9		5.74	5.38	6.25	6.05	23.42
10		5.51	4.80	8.00	5.59	23.90
11		4.47	3.89	5.26	4.52	18.14
12		3.40	2.54	3.20	3.56	12.70
13		2.34	1.32	2.03	2.57	8.26
14		1.37	0.58	1.14	1.65	4.74
15		0.53	1.10	0.41	0.86	1.90
1	Plot 2	0.00	0.00		0.56	0.56
2		0.43	0.18		1.57	2.18
3		1.17	0.86		2.95	4.98
4		2.01	2.03		4.01	8.05
5		3.33	3.76		5.03	12.12
6		4.80	5.72		5.84	16.36
7		5.79	6.63		6.68	19.10
8		8.76	6.65		7.57	22.98
9		5.66	6.65		6.02	17.73
10		5.59	5.72		5.31	16.62
11		4.65	3.99		4.39	13.03
12		3.45	2.54		3.40	9.39
13		2.41	1.24		2.39	6.04
14		1.24	0.46		1.52	3.22
15		0.51	0.00		0.86	1.37

APPENDIX B

Table B1. Dry plant weight at anthesis and kernels per plant at harvest.

1980		1981	
Dry Plant Weight At Anthesis	Kernels Per Plant	Dry Plant Weight At Anthesis	Kernels Per Plant
g		g	
43	0	83.8	386
99	440	96.8	439
110	512	102.7	513
130	446	104.0	473
42	0	96.3	418
81	83	86.3	346
111	475	89.2	333
133	492	95.0	456
105	400	91.2	512
35	67	82.7	477
51	222	86.7	262
139	539	75.0	349
137	546	104.3	435
39	247	87.2	489
81	517	92.0	455
106	397	93.2	438
86	357	91.8	422
48	144	100.2	409
		95.7	436
		86.2	461

1982		
Dry Plant Weight At Anthesis	Kernels Per Plant	Mean Dry Weight At Anthesis
140.0	399.4	317.7
136.0	410.2	319.4
158.0	449.1	345.6
167.0	543.7	362.3

APPENDIX C

Table C1. Irrigation level (IL) of the different plots combined to form an average irrigation application. 1980.

Simulated Irrigation Level	Sampling Location of Sprinkler-Line							
	Treatment 1		Treatment 2		Treatment 3		Treatment 4	
	IL	From SP*	IL	From SP	IL	From SP	IL	From SP
		cm		cm		cm		cm
1	1	1473	15	1473	1	1473	15	1473
3	3	1067	13	1067	3	1067	13	1067
5	5	660	11	660	5	660	11	660
9	9	152	7	152	9	152	7	152

* SP = Sprinkler-Line

Table C2. Average irrigation (cm) applied in simulation model.

Irrigation Level	1980 Dates 6/09	6/24	7/02	7/10	7/14	7/18	7/29	8/07	8/25	9/03
1	.05	0	.76	.36	.13	.23	0	.03	.03	0
3	1.07	1.30	2.47	1.40	1.88	2.13	1.65	1.65	2.29	1.47
5	4.37	4.95	4.85	3.05	3.60	5.74	5.61	5.66	3.68	4.32
9	8.07	7.54	9.98	4.37	5.13	8.79	7.42	8.03	5.36	4.95

1981

Irrigation Level	Dates 6/19	7/31
1	0.36	1.88
3	2.95	3.35
5	5.31	5.97
7	7.16	7.85

1982

Irrigation Level	Dates 7/06	7/26	8/12	9/01
1	0	0	0	0.76
3	1.35	0.91	0.69	2.74
5	3.51	3.61	3.81	5.66
7	5.94	5.31	5.23	6.55

APPENDIX D

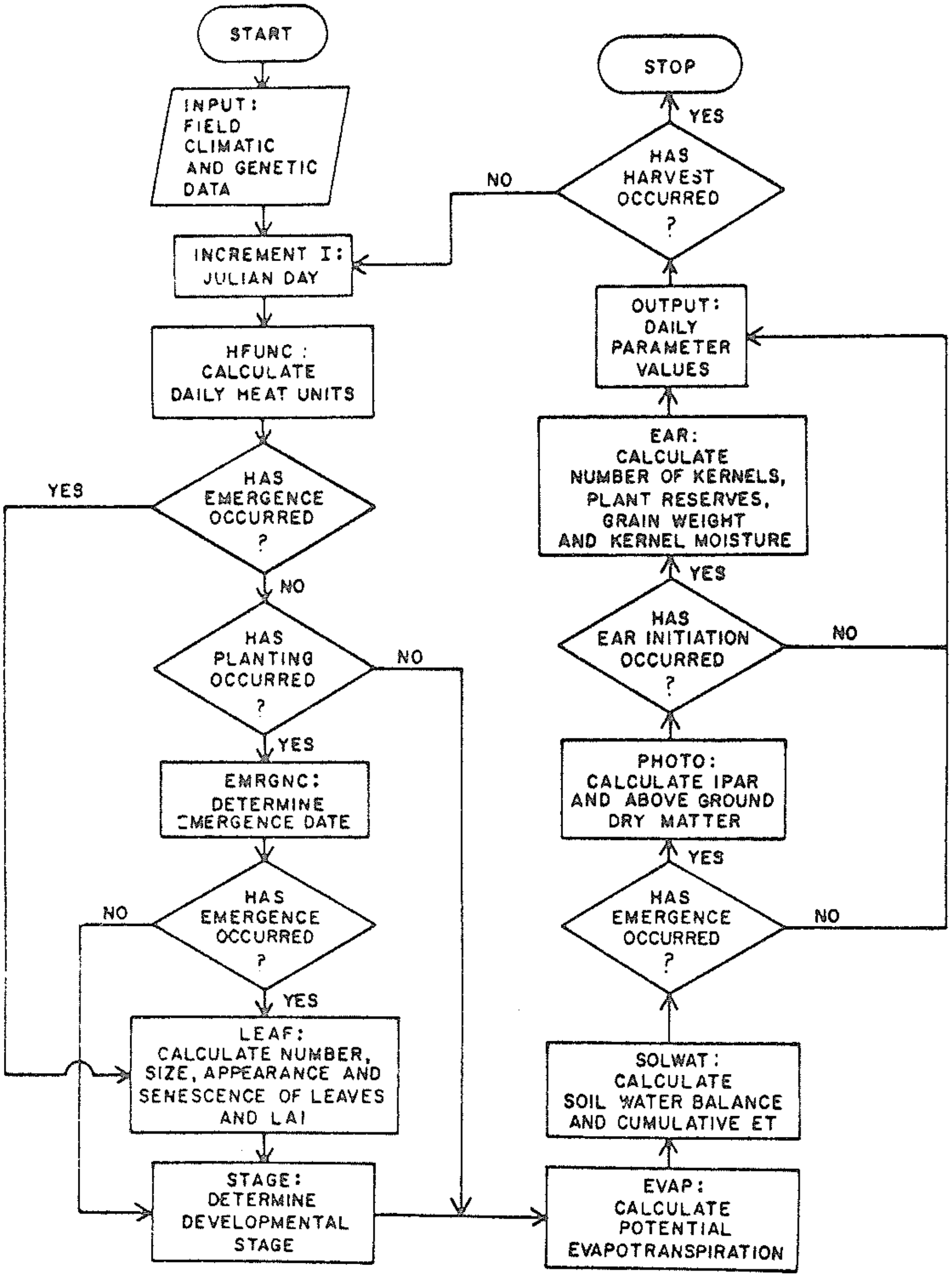

Figure D1. A flow diagram of a physiologically based corn model as described by Stapper and Arkin, 1980.