Scheduling Center Pivot Sprinkle... Corn Production in Eastern Colorado

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CENTER pivot irrigation systems are extensively used to irrigate new lands with textures ranging from coarse sand to silty clay loams. Because of low soil water holding capacities, coarse sandy soils require light, frequent irrigations, as many as 20 to 25 per season, for maximum crop production. Center pivot systems reduce labor requirements and are used on finer textured soils which can utilize larger, less frequent irrigations.

On coarse-textured soils many systems are operated continually to maintain a full soil water profile should the system malfunction. These soils usually have sufficient water holding capacity to allow 3- to 4-days "downtime" without seriously affecting crop yields. Systems designed to apply 2.5 cm per revolution on sandy soils tend to overirrigate both early in the season, when plant roots are shallow, and late in the season, when crop-water demand decreases.

On fine-textured soils, some irrigators (often with irrigation experience) tend to underirrigate by applying smaller depths of water at about the same frequency as that used for surface irrigation systems.

The USDA Irrigation Scheduling Program (Jensen 1971) takes into account the crop water requirements at various stages of plant development and outputs the irrigation date and amount to refill the profile at a preselected soil water depletion level. The USDA Irrigation Scheduling Program was modified to assist the farm manager in the decision-making process of when to **start** and **stop** a center pivot irrigation system. Our objectives in this paper are to discuss (a) these modifications to the scheduling program and (b) the performance of selected center pivot systems under this modified scheduling program, as measured both in terms of corn yield and deep percolation losses of water.

PROCEDURE

The USDA Irrigation Scheduling Program was modified to give multiple forecast dates for varying application depths and consecutive irrigations for the next week. The modified program was tested on four owner-operated center pivot sprinkler irrigation systems. Two irrigated farms are near Crook, and two are near Yuma, in Eastern Colorado. Soil type on the Crook farms (C and R) is Valent loamy sand; on the Yuma farms (F and M) is Ascalon fine sandy loam and Rago loam, respectively.

During the 1971 irrigation season, a computer output format for scheduling irrigations was developed for easy interpretation by farmer cooperators. Neutron access tubes were installed in several of the scheduled center pivot fields to monitor seasonal soil-water extraction and distribution. The estimated deep percolation is the difference between the summation of soil water extraction, rainfall and irrigation (measured water use), and estimated ET using the modified Penman equation in the irrigation scheduling prpogram.

Before the 1972 irrigation season, three vacuum extractors were installed at 1.5 m depths along a radial line of each of three center pivot systems on the loamy sand sites (C and R). The vacuum extractors (Duke and Haise 1973) consist of sheet metal troughs 20 cm deep by 15.2 cm wide and 3.25 m long with the top side open. A porous candle in the bottom of the trough, kept at a constant suction of 15-cm mercury, intercepts water lost to deep percolation beneath the root zone. Volumetric samples of the percolate were collected and withdrawn at weekly intervals.

Climatic input data for scheduling irrigations, which included maximum and minimum temperatures, dewpoint, wind speed, rainfall, and solar radiation, were measured in an area completely surrounded by center pivot irrigated corn fields (Fig. 1), except for solar radiation which was measured within 8 km of the scheduled fields near Crook and at Akron, Colorado, approximately 40 km from those near Yuma, Colorado.

Computer Output Format

The output of the modified scheduling program is presented in Fig. 2. The top (Fig. 2A—Update) of the output sheet is the update of the water budget computed with climatic data collected since the previous output. Tabulations include daily water use, irrigation and rainfall amounts, irrigation dates, and calculated soil water depletion at the **start** and **stop** positions (the two control positons under a center pivot system, Fig. 1). Automatic shut-off after each revolution usually provides a "start" from the same position. The recommended starting data on the printout (Fig. 2C—Schedule) is the day when expected soil water depletions at the starting point are greater than or equal to an irrigation depth. This is the earliest starting date that will avoid deep percolation losses.

The "no later than" date is the time when the system must be started to irrigate the **stop** position before the soil water depletion exceeds 50 percent of the available water in the root zone. Early in the season, because the minimum application depth is system limited, and the available water is computed on the basis of the effective root depth, the "no later than" date may be

Article was submitted for publication in September 1975; reviewed and approved for publication by the Soil and Water Division of ASAE in December 1975. Presented as ASAE Paper No. 73-2528.

Contribution from Agricultural Research Service, USDA, in cooperation with Colorado State University Experiment Station.

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This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 19, No. 2, pp. 284, 285, 286, 287, 293, 1976)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

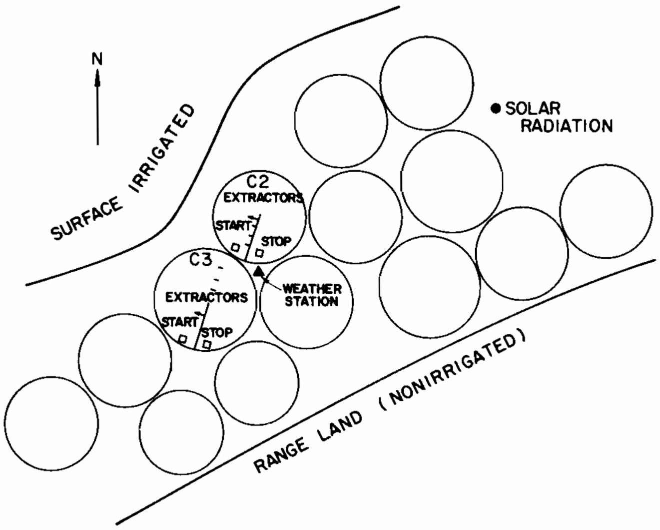

FIG. 1 Schematic showing location of weather station and two center pivot systems which were scheduled.

REGION CROOK

FARM CONDON NUMBER 2 CORN DATE AUG 10

A - UPDATE

DAY	WATER USED	IRRIGATION AND RAINS	IRRIGATION DATES	DEPLETION WHERE SYSTEM STARTS	DEPLETION WHERE SYSTEM STOPS
AUG 4	.15	0.00		.15	.15
AUG 5	.22	0.00		.36	.36
AUG 6	.26	.80	STARTED	0.00	.63
AUG 7	.27	0.00		.27	.09
AUG 8	.19	0.00		.45	.28
AUG 9	.25	.80	STARTED	0.00	.53
AUG 10	.28	0.00		.28	.01

B - FORECAST

MAXIMUM USEFUL RAIN AND IRRIGATION AMOUNTS

LARGER AMOUNTS WILL BE LOST

DATE	AMOUNT
AUG 11	.58
AUG 12	.88
AUG 13	1.17
AUG 14	1.45
AUG 15	1.68
AUG 16	1.90
AUG 17	2.11
AUG 18	2.32
AUG 19	2.53

C - SCHEDULE

IF THE SYSTEM APPLIES .8 INCHES AND MAKES A REVOLUTION IN 51. HOURS, THE RECOMMENDED STARTING TIMES ARE--

AMOUNT OF RAIN	START	NO LATER THAN
NO RAIN	AUG 13	AUG 19
0.25	AUG 14	AUG 20
0.50	AUG 15	AUG 22
1.00	AUG 17	AUG 24

*** *** *** *** *** *** *** *** *** *** ***

ASSUME THE SYSTEM WAS STARTED AUG 13
THE NEXT STARTING TIMES ARE -

AMOUNT OF RAIN	START	NO LATER THAN
NO RAIN	AUG 16	AUG 22
0.25	AUG 17	AUG 23
0.50	AUG 18	AUG 24
1.00	AUG 20	AUG 27

PROBABLE RAINFALL NEXT WEEK IS .28 INCHES

NOTE -- ALL WATER AMOUNTS ARE EXPRESSED IN INCHES IN THE ABOVE TABLES.

FIG. 2 Computer output submitted to the farmer indicating recommended weekly irrigation schedule.

before the recommended starting date. This can happen when the smallest application depth for a given system exceeds the water holding capacity in the root zone. The crop located in the stop position area continues to use water from the root zone during an irrigation and by the time an irrigation cycle is completed it may have a larger depletion than that desired. To avoid plant stress at the **stop** position, particularly during early growth stages, the **start** position should be irrigated sooner than the soil water depletion in the area reaches minimum application depth, even though there are some deep percolation losses.

Although the scheduling program is run on a weekly basis, several forecasted starting irrigation dates for the next week are computed. Alternate dates are given for the second and third irrigations assuming that the system had been started on the previously recommended **start** date. The operator must judge when to start a system. He has the latitude of starting the system anytime between the **start** and **no later than** date. On sandy soils, the center pivots generally are started on the first recommended **start** to maintain a full soil water profile and avoid excessive depletion should the system malfunction. The time interval between the **start** and **no later than** dates is generally smaller for coarse textured soils than for finer textured soils. Operators with finer textured soils tend to delay an irrigation until after the first recommended starting time which allows them to more effectively use any rainfall that may occur.

The center part (Fig. 2B—Forecast) indicates the maximum useful rain and irrigation amounts that could be applied at any given date. This part of the output represents estimated water use calculated from average climatic conditions for a given area. It is used by management to evaluate the effectiveness of rainfall which comes during the week and the actual timing of the irrigations. The 75 percent probable rainfall (Climatological) for the following week is also included, as additional information, to improve management.

The recommended irrigation starting times are also forecast, assuming a given amount of effective rainfall had fallen before the start of an irrigation. Forecasts are given for assumed rainfall amounts of 0.6, 1.2, and 2.5 cm. The effective rain is limited by the soil water depletion at the time of a rain. The amount of effective rain is determined by summing the total irrigation and rain on a given date during the forecast period and subtracting the maximum useful rain and irrigation amounts which are the forecasted soil water depletions (Fig. 2B—Forecast).

RESULTS

The irrigation scheduling program as modified for center pivots generally has been accepted by our cooperators, although each has different management objectives and uses the irrigation schedule differently. The cooperator whose management objective is obtaining maximum yields tends to start an irrigation at the first recommended starting time. Others who operate their systems more extensively to minimize irrigation and fertilizer costs tend to start their systems closer to the **no later than** date.

Table 1 summarizes the results of four cooperators using the irrigation scheduling program. Included are the dates, estimated ET, deep percolation (estimated and measured), irrigation, rainfall, and yield for each location and year. Differences between deep percolation losses measured with vacuum extractors (Duke and Haise 1973)

TABLE 1. RESULTS FROM CENTER PIVOT SYSTEMS WITH SCHEDULED IRRIGATIONS.

Location	Dates	Estimated ET	Measured water use	Deep percolation estimated	Deep percolation measured	Irrigation	Rain	Yield	
		cm	cm	cm	cm	cm	cm	Mg/ha)	bu/A
Coarse textured soils									
C-3	1971 June 3 - Aug. 25	45.5	58.2	12.7	—	48.3	9.7	8.1	128 Hail
C-3	1972 May 26 - Sept. 13	54.9	62.0	7.1	0.8	31.2	29.2	9.6	153
C-3	1973 May 25 - Sept. 13	56.9	65.5	8.6	2.3	41.4	20.1	12.6*	201*
C-2	1973 May 25 - Sept. 13	57.2	64.2	7.0	3.0	42.2	20.0	13.0*	207*
R-4	1972 May 26 - Aug. 23	47.5	54.6	7.1	6.4	32.8	20.8	11.2†	5T/A†Hail
R-4	1973 May 25 - Sept. 13	56.2	67.7	11.5	6.5	46.0	25.1	13.0*	207*
Fine textured soils									
F-1	1971 June 12 - Sept. 6	49.3	52.6	3.3	—	32.0	7.9	8.5	135 Hail
M-1	1972 June 23 - Sept. 6	35.6	40.4	4.8	—	12.4	19.6	7.5	120

*Plot yields in center of field.
†Silage yields.

for 1972 to 1973 on the C and R locations and those estimated were less than 10 percent of the total water used. This difference is probably less than the error in measurement of irrigation and rainfall and in the estimation of ET. The yield reduction on some sites was caused by hail and not by water or fertility management.

The 7.5 Mg/ha yield for the M-1 site was produced with rainfall and stored soil water plus only 12.4 cm of irrigation water which is approximately one-third to one-fourth of the irrigation water applied for the other sites. An estimated additional 6 cm of water would have been used if more irrigation water had been applied. The management objective here was to minimize costs and not to maximize yields.

The 1973 yields are from plots sampled on extractor sites in the middle of the center pivot fields. They are much higher than field-harvested yields for the entire circle because of harvest losses and non-uniformities of irrigation, soil, fertility and plant population in the field. Field harvested yields for 1973 ranged from 9.7-10.1 Mg/ha.

Location C-3 was scheduled for each of the 3 yr. During 1971, the operator often started the irrigation cycle 1 to 2 days earlier than recommended. Approximately 13 cm of excess irrigation water was applied. During 1972, he followed the schedule much closer (with more confidence) and the estimated deep percolation was reduced by almost 50 percent. The slight increase in deep percolation for 1973 over 1972 was caused by unexpected rainfall immediately after an irrigation. The water holding capacity at the C locations was approximately 1.2 mm/cm as compared with 0.7 mm/cm on the R

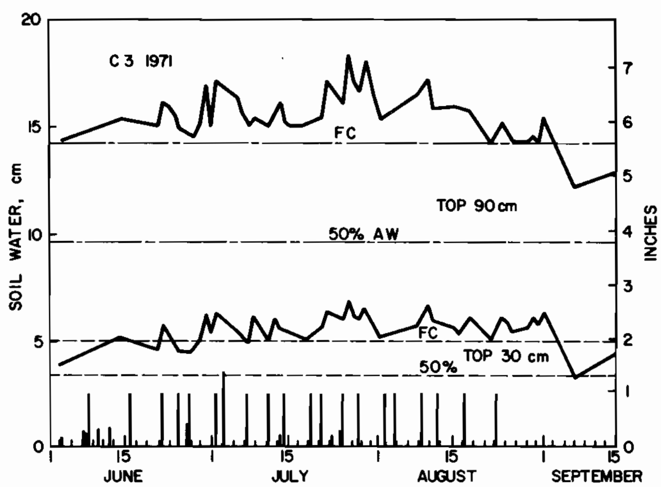

FIG. 3 The seasonal soil water content (solid lines) as measured with a neutron probe and the irrigation and rainfall (vertical lines) distribution for C-3, 1971.

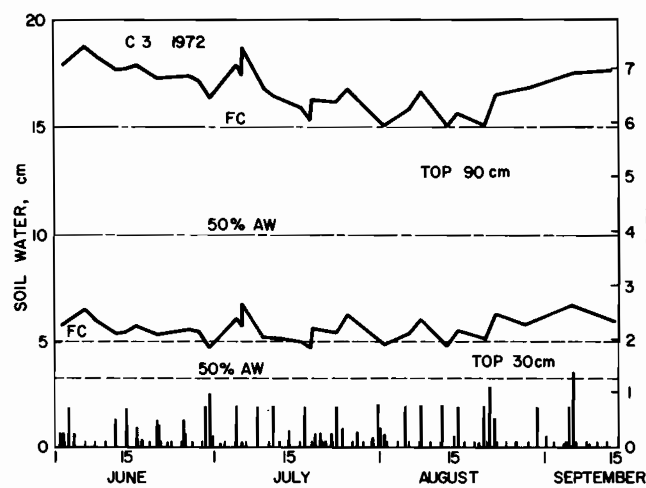

FIG. 4 The seasonal soil water content (solid lines) as measured with a neutron probe and the irrigation and rainfall (vertical lines) distribution for C-3, 1972.

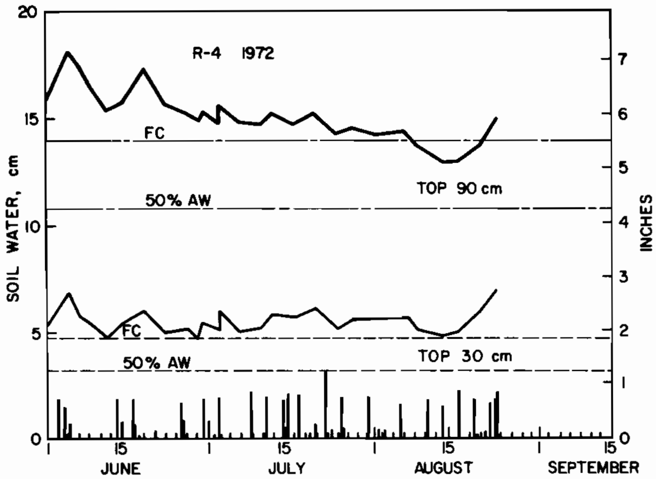

FIG. 5 The seasonal soil water content (solid lines) as measured with a neutron probe and the irrigation and rainfall (vertical lines) distribution for R-4, 1972.

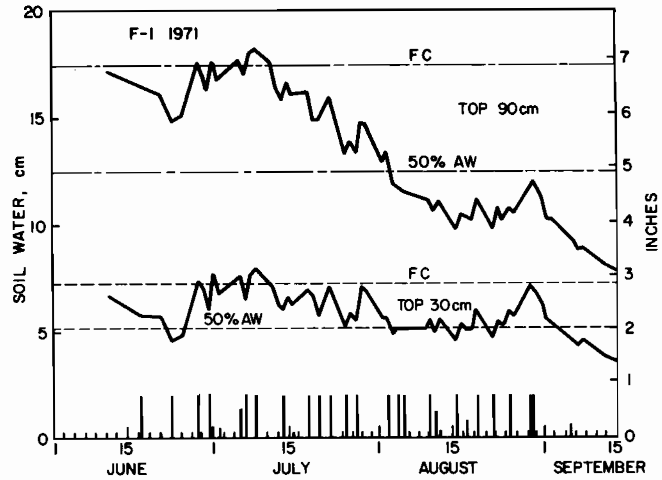

FIG. 6 The seasonal soil water content (solid lines) as measured with a neutron probe and the irrigation and rainfall (vertical lines) distribution for F-1, 1971.

location.

Soil water content as measured with a neutron probe was generally above field capacity (FC—assumed to be the soil water content 4 days after an irrigation on bare soil) for C-3 in 1971 (Fig. 3) and 1972 (Fig. 4). Irrigations on a less than 4 day cycle maintained the soil water content above field capacity. A finer textured soil layer near the 90 cm depth slowed the rate of drainage and allowed more time for the crop to use the water.

The estimation of deep percolation losses from soil water content is difficult, as illustrated by the seasonal trends for 1971 and 1972 (Figs. 3 and 4) where the deep percolation was reduced by 50 percent. This is particularly true when the soil water content is maintained near field capacity with frequent irrigations. Field capacity was higher for 1972 due to relocation of the sampling plots within the irrigated circle. To obtain high uniform yields over the entire circle, large variations in soil water holding capacity must be considered before setting up an irrigation scheduling program. The areas with the lowest water holding capacity are important in selecting the frequency and depth of irrigation. On coarse-textured soils, the soil water content must be maintained because available soil water is very limited.

In 1972, irrigations were scheduled for R-4 (Fig. 5) which has a lower soil water holding capacity than C-3 (Figs. 3 and 4). The measured deep percolation loss was slightly larger for this system than for C-3 (Table 1). The irrigation season was short since the corn was damaged by hail and harvested for silage in August. Frequent irrigations were required to maintain the soil water near field capacity. The limited soil water holding capacity could be depleted within 3 to 4 days of extreme high water use. Thus, maintaining a full profile to minimize the chance of a crop failure was essential should a system malfunction. The total available water in the top 60 cm of the soil profile could easily be depleted during a 1-wk period in July without irrigations.

The cooperator who started the system later than the recommended starting time but before the **no later than** date, depleted the soil water throughout the season (Fig. 6). The frequency of irrigation maintained a fairly high water content in the top 30 cm but resulted in a significant reduction of water in the top 90 cm of the profile.

SUMMARY AND CONCLUSIONS

The USDA Irrigation Scheduling Program was modified to provide multiple irrigation forecast dates for use with center pivot sprinkler irrigation systems. Four Eastern Colorado cooperators used the program and developed confidence in the computer output mailed to them weekly. Each cooperator used the information slightly differently. Some cooperators started the irrigation system at the earliest recommended date, whereas others started their systems between the **start** and **no later than** date. The two dates provided were (a) the **start** date when the soil water depletion was equal to the irrigation depth, and (b) the **no later than** date when the system must be started so as not to deplete 50 percent of the available soil water at any location in the field. The cooperator who participated for 3 yr (C-2, C-3) reported that his yields had definitely increased due to the scheduling program. Thus, the scheduling program certainly can be beneficial to center pivot irrigation by increasing yields and conserving energy, water and fertilizer (in the deep percolation). Coarser textured soils should be irrigated as soon as the soil is depleted sufficiently to hold an irrigation. Here, irrigation application depths of less than 15 mm/revolution are advantageous early in the season. Usually the irrigation depth is increased to approximately 25 mm/revolution during the latter part of June. On the finer textured soils, application depths of 75 mm/revolution are recommended.

The use of a calculated water budget, like the USDA Scheduling Program, seems to have greater advantages on coarse-textured soils. The soil water is depleted very rapidly and soil water measurements must be made very frequently. Overlooking soil variability within a field can lead to misinterpreting soil water measurements, unless successive measurements are made at the same location.

OUTLOOK

The expanded use of the center pivot scheduling program will require adoption by a consulting service. For several seasons, the scheduling program has estimated

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the soil water depletion satisfactorily and did not require adjustments from the neutron probe measurement of soil water depletion. The program requires an accurate feedback of rainfall and irrigation amounts. The cost and benefit of this program is difficult to assess since the current management ability of farmers is highly variable. Water management is only one part of the total management required for improved crop production.

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