Scheduling Irrigation for Corn and Soybean in the Southeastern Coastal Plain

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ABSTRACT

CORN (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) were grown on an 18-ha site near Florence, SC, under irrigated and nonirrigated conditions for a 3-year period (1979 to 1981). The three irrigation scheduling methods were, for corn, tensiometer (TENS), screen-covered evaporation pan (SPE), and computer-based water balance (CBWB); and, for soybean, TENS, SPE, 70% of screen-covered pan evaporation (0.7 SPE) in 1979 and 1980, and CBWB in 1981. A treatment that received only rainfall was included for both corn and soybean each year. Rainfall was near normal in 1979, below normal in 1981, and much below normal in 1980. Yields for irrigated treatments were higher than for nonirrigated treatments each year for corn, but yields for only some of the irrigated treatments were higher for soybean. There were generally no significant differences in mean corn and soybean yields among the three irrigation scheduling treatments. There were no consistent differences in mean volume of irrigation water required by the three scheduling methods for all 3 years, although, for soybean, SPE tended to require the most irrigation water and TENS tended to require the least irrigation water. Because no significant differences in water requirement or yield were found for the three scheduling methods, the choice among them is essentially a matter of personal preference until refinements are made in one or all of the methods. The CBWB method does offer the advantage of predicting irrigation requirements up to 5 days ahead, if weather forecasts are available.

INTRODUCTION

Irrigation usage in the southeastern Coastal Plain has increased significantly during the past 10 to 15 years, particularly for corn. At least every other year irrigation is necessary because of poor rainfall distribution and coarse-textured soils with low water storage capacities, which result in yield-reducing drought periods. Compacted soil layers often restrict plant rooting and further reduce the water volume available to plants if subsoiling is not used (Campbell et al., 1974). Although several irrigation management methods are available, only a few irrigation managers in the region use them. Tensiometers and evaporation pans have been recommended (Bruce et al., 1980; Rhoads, 1982; Westesen and Hanson, 1981; Doty et al., 1982) but have not been widely used in the southeastern U.S. (Lambert, 1980).

Computers have been used in arid regions for several years to compute water balances and to estimate daily ET from weather data (Jensen et al., 1970; Kincaid and Heermann, 1974). This technology has not been widely accepted in humid regions although it offers the potential for considering rainfall probability in irrigation scheduling, for application to a wide range of soil, crop, and climate conditions, and for forecasting irrigation several days in advance. Neither irrigation scheduling techniques nor methods to estimate daily ET have been evaluated over a wide geographic area in the region (Sadler and Camp, 1986). A scheduling procedure for use on personal computers was evaluated for corn at Coastal-Plain sites in four states and was compared with irrigation scheduled using tensiometers (Hook et al., 1984; Camp et al., 1985; Hook, 1985; Cassel et al., 1985). The purpose of this research was (a) to evaluate a computer-based water balance irrigation scheduling technique and (b) to compare growth, yield, and irrigation water requirements for corn and soybean under various irrigation management methods.

METHODS

Corn [*Zea mays* (L.) cv. Pioneer 3369-A] and soybean [*Glycine max* (L.) Merr. cv. Bragg] were grown on an 18-ha site near Florence, SC, where the major soils are Bonneau loamy sand (Arenic Paleudult) and Norfolk loamy sand (Typic Paleudult). These soils had a compacted E horizon 20 to 60 mm thick at a depth of 0.20 to 0.30 m. Four water management treatments and five tillage treatments were included in the study during the 3-year period, 1979 to 81; however, only the mean of two tillage treatments (conventional and conservation tillage, both with subsoiling) are reported here. Complete tillage results for this study were reported by Camp et al. (1984). The four water management treatments were three irrigation scheduling methods and one treatment (NI) where no irrigation was applied. For corn, the three irrigation scheduling methods were (a) a computer-based water balance method (CBWB), (b) a screened pan evaporation method (SPE), and (c) a tensiometer method (TENS). For soybean during the first 2 years, the three irrigation scheduling methods

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were (a) a screened pan evaporation method (SPE), (b) a tensiometer method (TENS), and (c) screened pan evaporation where only 70% of the water lost from the evaporation pan was replaced by irrigation (0.7 SPE). In the third year, 1981, the CBWB method replaced the 0.7 SPE method.

The CBWB method utilized a water balance procedure adapted to a microcomputer, the same as that used by Hook et al. (1984), Camp et al. (1985), and Cassel et al. (1985). This method utilized daily maximum and minimum temperatures, solar radiation, rainfall, and irrigation to calculate ET and volumetric soil-water content. A single soil-water retention relationship was used for all plots within the CBWB treatment, and ET was estimated using the modified Jensen-Haise method (Jensen et al., 1970). Daily allowable depletion and rooting depth values were also required. Allowable depletion was 50% of total available water for all 3 years. In 1979, the rooting depth was assumed to be constant at 0.60 m. In the other 2 years, it was estimated, from experience and periodic observations of root systems, to increase stepwise from 0 at planting to a maximum of 0.70 m. The CBWB was operated twice weekly, each time calculating daily ET and soil-water storage values for each of the next 5 days using forecast temperature and solar radiation data provided by the National Weather Service. The goal was to maintain root zone soil-water content between 50 and 90% of total available water.

The screened pan evaporation (SPE) method utilized a screen-covered evaporation pan to estimate potential evapotranspiration (Campbell and Phene, 1976; Doty et al., 1982). Irrigation was initiated when the water level in the screen-covered evaporation pan dropped to a preset level below the overflow. The major soil in the irrigated area with the smallest volume of available water in the rooting zone (54 mm) was used to calculate the allowable depletion using published values of upper and lower limits of available water. The active rooting zone was estimated to be 0.70 m, and irrigation was initiated before 50% of the available water in the rooting zone was depleted. Therefore, irrigation was applied when 27 mm (50% × 54 mm) of water had evaporated from the pan. After irrigation, a water depth corresponding to the effective irrigation depth was added to the evaporation pan. Rainfall in excess of the simulated soil storage was wasted via an overflow. In the 0.7 SPE method, irrigation timing was determined in the same manner as in the SPE method; however, only 70% of the water depleted from the evaporation pan was replaced by irrigation.

In the TENS method, irrigation was initiated when tensiometers at selected depths in any two plots (of six) exceeded a predetermined soil-water tension (SWT) value. In 1979, the SWT value was 30 kPa at the 0.30-m depth for corn; while in 1980 and 1981, it was 25 kPa at the same depth. For soybean, the SWT value was 50 kPa at the 0.30-m depth or 20 kPa at the 0.45-m depth in 1979 and 30 kPa at the 0.30-m depth in 1980 and 1981.

Generally, irrigation amounts for all treatments were 20 to 30 mm for each event. The irrigation system was capable of applying 25 mm of water to each sector (one treatment) every 4 h. Consequently, all three treatments for a single crop could be irrigated within a single day, but generally, irrigation was not required on more than two treatments on a given day. When multiple treatments required irrigation on the same day, irrigation sequence was dictated by the initial center pivot location and treatment locations; however, irrigation application time was minimized and the sequence tended to be random over the growing season.

Corn and soybean were grown separately, each in a quadrant of a high-pressure center pivot irrigation system, and were rotated between the two quadrants each year. For each crop, each irrigation treatment was located in one of three sectors within the quadrant (Fig. 1). Tillage treatments were the same for both corn and soybean and remained in the same location each year, although crops and irrigation treatments were changed. Nonirrigated treatments were located immediately adjacent to the center pivot system (Fig. 1). Four blocks, each of which contained all tillage treaments, were located within each sector (irrigation scheduling treatment) and the nonirrigated area. These four blocks provided replication for tillage treatments but did not provide true replication for irrigation treatments. Because true replication of irrigation treatments was not obtained, yield data were analyzed for year and irrigation effects for each crop separately using analysis of variance (ANOV), least significant difference (t test), and contrasts. In the ANOV, a randomized complete block design was used with year as the block, and treatments were assigned within the year. Although irrigation treatments were not in different locations (another center pivot) each year, they were in a different quadrant of the same system for one year and were randomized within the quadrant. This means that treatments were not necessarily in the same sector, although in the same quadrant in 1979 and 1981. In some cases, soil variation was as great within a sector (among four blocks) as it was among sectors.

All treatments were subsoiled in the row to a depth of 0.40 m and were planted using a six-row, in-row subsoiler-planter unit (Brown-Harden Super Seeder with John Deere-71 Flexi-planters) in rows spaced 0.98 m apart. Annual application of N, P, and K fertilizer averaged 240, 62, and 174 kg/ha for corn and 16, 35, and 107 kg/ha for soybean, respectively, for all treatments. Mean plant populations at harvest were 72,900 and 57,500 plants/ha for irrigated and nonirrigated corn, respectively, and 237,600 plants/ha

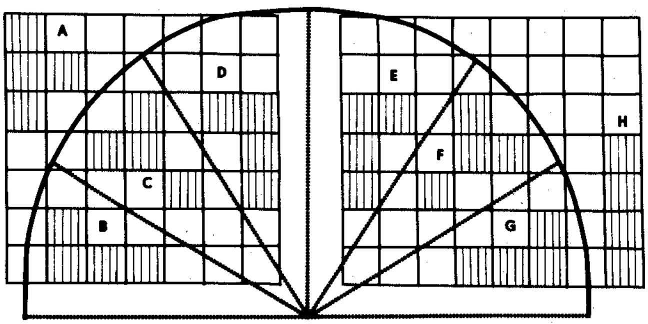

Fig. 1—Irrigation treatment locations within the center pivot system (B,C,D,E,F,G) which could be irrigated independently. Tillage treatments are shown schematically as strips within the squares with the nonirrigated treatment areas (A,H) located outside the center pivot area.

for soybean. Seeding rates and pesticides were applied in accordance with South Carolina Cooperative Extension Service recommendations. Corn seeding rates were different for irrigated and nonirrigated treatments.

Tensiometers were installed at depths of 0.15, 0.30, 0.45, 0.60, and 0.90 m in two blocks of each irrigation treatment (total of 29). Tensiometer measurements were recorded three times each week during the growing season. Rainfall and irrigation water applied were measured on site, but other meteorological data required for the CBWB procedure and pan evaporation were measured at a weather station located about 8 km from the site. Irrigation was measured using a non-recording rain gauge located in an open area within the irrigated crop canopy at a height of about 1.5 m. Twenty- or 30-m row segments of each of the four center rows of each plot were harvested and weighed for yield determination using a two-row or four-row combine for corn and soybean, respectively. Corn grain and soybean seed yields were corrected to 15.5 and 13% moisture, respectively.

RESULTS AND DISCUSSION

Corn Irrigation

Rainfall and irrigation received during the corn growing season for each of the 3 years (1979 to 81) are included in Table 1. Rainfall distribution during the corn growing season in 1979, 1980, and 1981 is shown in Fig. 2. In 1979, rainfall was adequate to satisfy ET until early June, when irrigation was initiated. Although rainfall occurred intermittently, irrigation was required for the remainder of the growing season. In 1980, rainfall during the growing season was much less, particularly during the vegetative stages, and irrigation was required every month. Total rainfall for this growing season (227 mm) was lowest of the 3 years. In 1981, adequate rainfall occurred during the early vegetative growth stage but was deficient later in the growing season. Significant irrigation was required during pollination and grainfill, critical times for corn (June and July), because of low rainfall.

In 1979, the SPE treatment required the most irrigation (192 mm), while the CBWB treatment required the least amount (121 mm) (Table 1). Major reasons for a low irrigation requirement in the CBWB treatment were corrections to the computer program and

TABLE 1. IRRIGATION OR RAINFALL DURING THE CORN GROWING SEASON FOR 1979 TO 1981

Year	Water management treatment*			
	CBWB	SPE	TENS	NI
	mm			
1979	121 (3)†	192 (5)	158 (4)	427
1980	333 (10)	297 (9)	325 (10)	227
1981	213 (8)	177 (7)	269 (10)	365
Mean	222	222	251	340

*CBWB=computer-based water balance, SPE=screen-covered pan evaporation, TENS=tensiometer, and NI=nonirrigated, rainfall only. Rainfall must be added to irrigation to obtain total water applied to irrigated treatments.

†Numbers in parenthesis reflect number of irrigation applications greater than 6 mm.

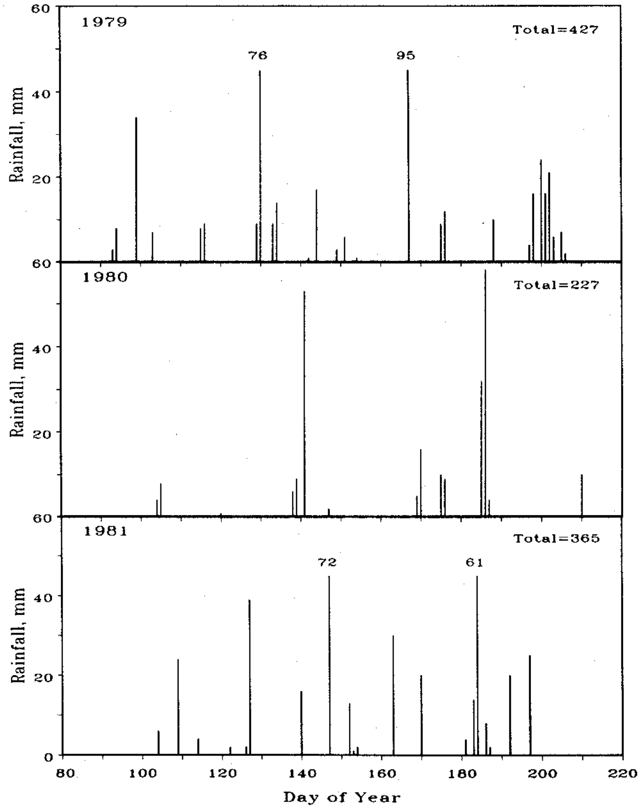

Fig. 2—Daily rainfall amounts for corn during the growing season in 1979, 1980, and 1981. Numbers printed above daily rainfall lines indicate values which exceed the plotting range.

changes in parameter values, normal adjustments associated with the initiation of a new computer program. In 1980, the CBWB and TENS treatments required almost equal amounts of irrigation, while the SPE treatment required about 30 mm less irrigation water. This was the driest year of the study, which resulted in fairly uniform intervals between irrigations for all treatments. In 1981, the TENS treatment required the greatest amount of irrigation water, and the SPE treatment required the least amount. Seasonal rainfall for this year was intermediate between the two previous years but was within 62 mm of that for the wettest year, 1979.

Irrigation water applied during the 3 years varied considerably as did rainfall, but no one scheduling method required the most water all years. When mean seasonal irrigation amounts for the 3-year period are considered, the TENS treatment required more irrigation water than the other two methods, which required equal amounts. There were some differences in soils for the irrigation treatments among the 3 years because irrigation treatments were rotated among the six sectors of the center pivot system. Soil-water storage values for the CBWB and SPE treatments were based upon major soil types under the irrigation systems and were not changed each year, when treatment locations were changed. On the other hand, the TENS treatment was directly affected by soil changes each year because tensiometers were located in the treatment areas and reflected the soil-water potential at that location. This could account for some of the variation in irrigation water required by the TENS treatment although this variation was no greater than that for other treatments. Also, some variation in the irrigation water applied was caused by the randomness of rainfall. For example, one method might require irrigation on a given day and another method would require irrigation the following 1 to 3 days, but rainfall after noon of the first day or during the next day would preclude the need for irrigation on the following days. This sequence of events occurred at least four times during the 3-year long study, affecting the SPE (3 times) and CBWB (2 times) treatments more than the TENS treatment (1 time). Additionally, if runoff occurred during high intensity storms or if more excess water was lost via profile drainage than that estimated by the CBWB and SPE methods, these methods would overestimate stored soil water and would require less irrigation than the TENS treatment.

Measured irrigation and rainfall and calculated upper and lower limits of available soil water, critical level of available water, and daily soil water content (SWC) for the CBWB treatment in 1980 are shown in Fig. 3. Calculated values were obtained from the CBWB operated in batch mode at the end of each season using only measured weather data. The results for 1980 are similar to those for the other 2 years of the study. Because the SWC values in Fig. 3 were calculated during a post-season operation of the CBWB using only measured weather data, they are not necessarily the same as those calculated during bi-weekly growing-season operations of the CBWB using both measured (past) and forecast (future) weather data, which were used to schedule daily irrigation applications. The soil water volume available to plants is a function of rooting depth, consequently this volume increases during the season from planting until it reaches a maximum. Generally, the calculated SWC values remained within the target control zone, between the upper limit of available water (UL) and the critical level (CL), all 3 years.

Potential ET (PET, now commonly referred to as reference ET) and actual ET (AET) values calculated by the CBWB procedure for equal time periods (May 22 to July 31) are 404 and 322 mm, 453 and 307 mm, and 446 and 348 mm for 1979, 1980, and 1981, respectively. AET values calculated by the CBWB procedure for the nonirrigated treatments are 231, 164, and 275 mm for the same time periods.

Soil-water potential data, as determined by tensiometers, could not be used to accurately estimate volumetric soil-water content because of soil variation within and among treatments; therefore, simulated and measured soil water contents could not be compared. Also, tensiometer data were not sufficient in scope and number to estimate water loss via deep percolation; however, losses of this type probably occurred, particularly during periods of high soil water content.

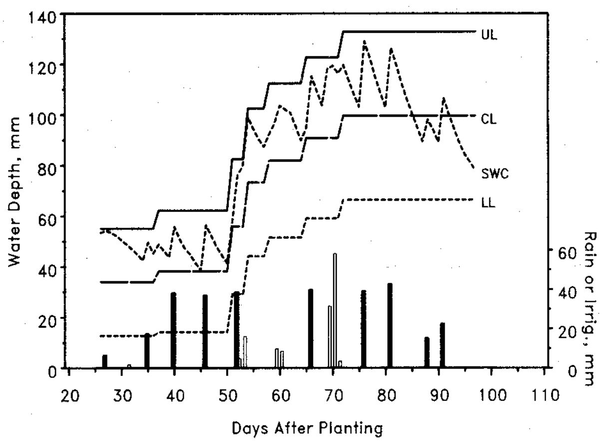

Fig. 3—Seasonal water balance for corn in Florence, SC, for 1980. Upper limit (UL), lower limit (LL), and critical level of available soil water (CL); computed soil water volume stored in the profile (SWC); and daily rainfall (open bars) and irrigation (solid bars) for CBWB treatment.

Corn Yield

Corn grain yields were consistently higher every year for the irrigated treatments than for the nonirrigated treatment, and mean yields for the 3-year period were significantly higher for the irrigated treatments. When yields for the irrigated treatments were pooled and contrasted with yields for the NI treatment, a significant ($P=0.05$) effect was found. In the 3-year period, neither of the three scheduling methods consistently produced the highest or lowest yields. Three-year mean corn grain yields for the three scheduling treatments were not significantly different (Table 2).

In 1979, the highest yield (10.35 Mg/ha) was measured on the SPE treatment, which received the greatest amount of irrigation water (192 mm), but was followed closely by the TENS treatment (9.75 Mg/ha), which received 158 mm of irrigation water. Yield for the CBWB treatment (8.60 Mg/ha) was lowest of the three scheduling methods and received the lowest amount of irrigation water (121 mm) (Table 2). Although computer program changes in 1979 caused some difficulty in the proper application of irrigation to the CBWB treatment, corn grain yield for this treatment was higher for this year than for the second year of the study. In 1980, corn grain yields were highest on the CBWB and TENS treatments (7.71 to 7.91 Mg/ha), both of which received about 40 mm more irrigation water than the SPE treatment, which produced a lower yield (6.15 Mg/ha). Temporary periods of soil saturation caused by excessive irrigation or rainfall following irrigation probably occurred this year and caused a measured potassium deficiency in corn plants. This resulted in excessive lodging and may have reduced yields for all irrigated treatments.

In 1981, corn grain yields for all three irrigation scheduling treatments were similar (8.64 to 9.03

TABLE 2. MEAN CORN GRAIN YIELDS FOR WATER MANAGEMENT TREATMENTS IN COASTAL PLAIN SOILS IN 1979 TO 81

Year	Water management treatment*			
	CBWB	SPE	TENS	NI
	Mg/ha			
1979	8.60	10.35	9.75	6.64
1980	7.71	6.15	7.92	3.03
1981	9.03	8.88	8.64	4.60
Mean	8.45a†	8.46a	8.77a	4.76b

*Treatments are same as defined in Table 1.
†All means followed by the same letter are not significantly different at the P=0.05 level according to LSD test (or t test).

Mg/ha), although there was a maximum difference of 56 mm in irrigation water applied. Although it appeared that corn grain yield was related to the amount of irrigation water applied in 1980, this was not the case in 1981, when the greatest amount of water was applied in the TENS treatment, but the highest yield was produced in the CBWB treatment. From these data, it appears that factors other than irrigation and rainfall affected yields for these treatments. Soil variation was probably the major factor contributing to this variance.

The water supply for the center pivot system failed on 29 June 1981. This resulted in reduced irrigation amounts for all treatments until 3 July, when rainfall partially replenished the water supply. Plant stress during this period was moderately high and probably reduced yield, but the effect was estimated to be equal among the three irrigation scheduling treatments because all had been irrigated last within 2 days of each other. The existence of more periods of drought stress in 1980 and 1981 reduced corn yields on the NI treatment and may have reduced yields even on irrigated treatments, which indicates that irrigation applications were not precisely matched with need.

Soybean Irrigation

Seasonal irrigation and rainfall amounts for soybean in all 3 years are reported in Table 3. Daily rainfall distribution during the growing season for 1979, 1980, and 1981 is shown in Fig. 4. Seasonal rainfall was highest in 1979 (642 mm), but irrigation was required during much of the season, beginning about 15 July. In 1980, seasonal rainfall was much lower (448 mm), and irrigation was required throughout most of the season, beginning about 15 June. Seasonal rainfall increased slightly in 1981 (500 mm) but remained much lower than that observed in 1979. Seasonal irrigation amounts were much lower in 1981, and irrigation was required primarily during two time periods, one in late July and another in September.

Although none of the irrigation scheduling methods consistently required more or less water for all 3 years, the most irrigation water was required by the SPE method for 2 years (1980, 1981) and by the 0.7 SPE and SPE methods in 1979. The TENS method required the least amount of irrigation water 2 years (1979, 1980) and only 5 mm above the lowest amount in 1980. The 3-year mean irrigation amounts indicate slight differences among the scheduling methods (52 mm maximum), with the SPE method requiring the most water (242 mm) and the TENS method requiring the least water (190 mm).

TABLE 3. IRRIGATION OR RAINFALL DURING THE SOYBEAN GROWING SEASON FOR 1979 TO 1981

Year	Water management treatment*			
	0.7SPE-CBWB	SPE	TENS	NI
	mm			
1979	200 (6)†	198 (5)	124 (3)	642
1980	303 (9)	350 (11)	308 (9)	448
1981	164 (6)	178 (7)	138 (5)	500
Mean	222	242	190	530

*SPE=screen-covered pan evaporation, 0.7 SPE=apply 70% screened-pan evaporation (1979-80), and CBWB=computer-based water balance (1981), and NI=nonirrigated (rainfall only). Rainfall must be added to irrigation to obtain total water applied to irrigated treatments.

†Numbers in parenthesis reflect number of irrigation applications greater than 6 mm.

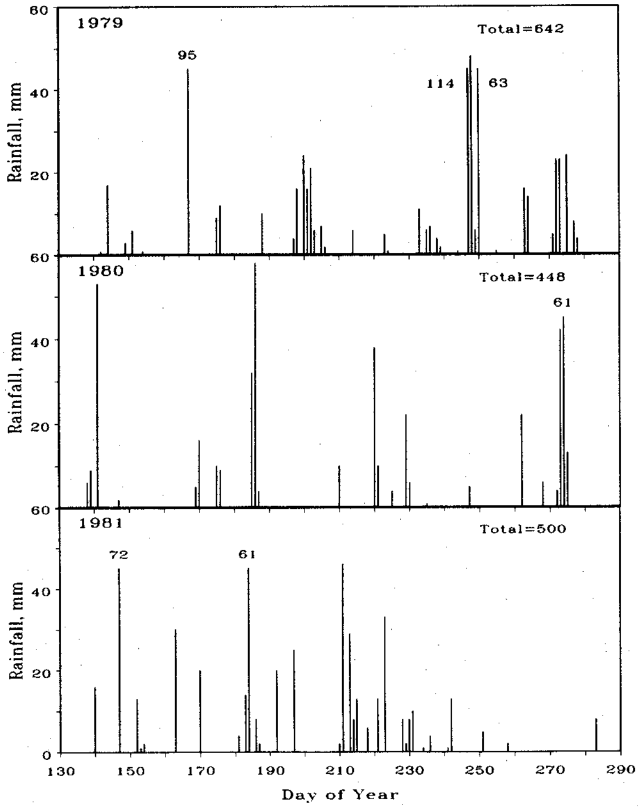

Fig. 4—Daily rainfall amounts for soybean during the growing season in 1979, 1980, and 1981. Numbers printed above daily rainfall lines indicate values which exceed the plotting range.

Much of the discussion regarding variance in irrigation water amounts among the irrigation scheduling treatments for corn also apply for soybean. The additional irrigation scheduling treatment for soybean (0.7 SPE) should require irrigation amounts similar to those for the SPE treatment during periods with little or no rainfall, but irrigation would be required more frequently. An advantage of this method is that it provides more soil storage for rainfall immediately following irrigation which would be lost as runoff in the SPE method. During periods with frequent rainfall the 0.7 SPE method should require less irrigation than the SPE method because only 70% of the water loss is replaced with irrigation and any significant rainfall should be more efficiently utilized and stored.

Soybean Yield

In 1979, the highest soybean yield was measured on the SPE treatment (2.63 Mg/ha), which received 198 mm of irrigation water, but yields for the other two scheduling methods and the NI treatment were similar (1.73 to 1.95 Mg/ha). One of the lower-yielding irrigated treatments (0.7 SPE) received slightly more irrigation water (2 mm) than the treatment (SPE) with the highest yield. In 1980, soybean yields for all three scheduling methods were similar (2.32 to 2.49 Mg/ha), although there were substantial differences in irrigation water

TABLE 4. MEAN SOYBEAN SEED YIELDS FOR FOUR WATER MANAGEMENT TREATMENTS IN COASTAL PLAIN SOILS IN 1979 TO 81

Year	Water management treatment*			
	0.7 SPE-CBWB	SPE	TENS	NI
	Mg/ha			
1979	1.76	2.63	1.95	1.73
1980	2.45	2.32	2.49	1.25
1981	2.10	2.39	2.00	1.63
Mean	2.10ab†	2.45a	2.15a	1.54b

*Treatments are the same as defined in Table 3.
†All means followed by the same letter are not significantly different at the P=0.05 level according to LSD test (or t test).

applied (47 mm maximum). Yields for all irrigated treatments were higher than that for the NI treatment (1.25 Mg/ha). In 1981, yields were highest for the SPE treatment (2.39 Mg/ha), which also received the most irrigation water, and were lowest for the NI treatment (1.63 Mg/ha). There were no significant differences among the 3-year mean yields for the three irrigated treatments, and yields for all except the 0.7 SPE-CBWB treatments were significantly higher than that for the NI treatment.

Generally, soybean response to irrigation was not as great in magnitude nor as consistent as was the corn response. The high variability in yield among the treatments, plots, and years experienced in corn was also evident in soybean, for many of the same reasons. The lower response level to irrigation for soybean was probably due to the longer fruiting period of soybean, the more buffered characteristic of this plant to drought stress, and, possibly, a difference in photosynthetic capacity.

SUMMARY AND CONCLUSIONS

Irrigation water required by the three irrigation scheduling treatments varied considerably for the 3-year study, but no method consistently required the highest or lowest amounts of water for corn. Some differences in amount of irrigation water applied were caused by the random occurrence of rainfall, because there was usually a 1-to-3-day difference in the time irrigation was required by the three methods, and rainfall often occurred during that time period. This removed the need to irrigate those treatments that had been scheduled during the later part of the period. The 3-year mean seasonal irrigation totals for corn were very similar for the three scheduling methods. Likewise, there were no significant differences in the 3-year mean corn grain yields among the three methods, but all were significantly higher than for the NI treatment. Yield differences among the irrigation scheduling treatments were greatest in 1979 and 1980, but again, no method consistently produced the highest or lowest yield.

For soybean, the SPE method tended to require more irrigation water, and the TENS method tended to require less during the 3-year period of this experiment. Soybean was more tolerant of drought stress than corn, and yield was not always higher for irrigated treatments than for the NI treatment. In the driest year, 1980, soybean yields for the three scheduling treatments were similar, and all were higher than yield for the NI treatment. Three-year mean soybean yields for the three scheduling methods were not significantly different, but all except that for the 0.7 SPE-CBWB treatment were higher than that for the NI treatment.

All irrigation scheduling methods evaluated in this experiment performed satisfactorily, and there were no consistent differences in the amount of irrigation water required. Therefore, until refinements are made in these methods of scheduling irrigation, the farm manager may choose the method best suited to his needs.

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