The *Journal of Cotton Science 10:210–223 (2006)*
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ENGINEERING AND GINNING

Calibration and Use of the UGA EASY Evaporation Pan for Low Frequency Sprinkler Irrigation of Cotton in a Clay Soil

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ABSTRACT

A new irrigation scheduling tool called the UGA EASY Pan (Evaporation-based Accumulator for Sprinkler-enhanced Yield) allows remote observation of evaporation that can be correlated with crop water use. The pan was developed at the University of Georgia and was evaluated in Mississippi for low frequency irrigation of cotton in clay soils. To establish a baseline trigger level for irrigation, granular matrix soil water sensors were placed at three depths and four stations in a 3-ha field planted in a Sharkey series clay soil. Stoneville BXN 47 was planted for the 2002 and 2003 seasons and Stoneville 4892 BR was planted for 2004. Pan use and temporal adjustment criteria were developed during the 2003 season and further evaluated using data from 2004 and the previous year (2002). Irrigation was initiated based on field manager recommendations without assistance from scheduling aids so that pan readings could be associated with the field manager's irrigation decisions. Recommendations were made for temporal adjustment of the pan taking into account increased evapotranspiration based on sensor data analyzed post-season. To account for increased crop water demand in 2003 and 2004, a recommendation was made for a second adjustment approximately 97 days after planting (DAP) or 28 days after white bloom. This additional adjustment was also verified to be suitable to signal irrigation 112 DAP (43 days after white bloom) in 2003 that coincided with a trigger signal from sensor readings. Based on subsequent analysis of sensor readings as a baseline reference, one irrigation could have been delayed and another eliminated for 2003 (a 25% water savings), and the first irrigation could have been eliminated for 2004 (a 33% water savings) if pan recommendations had been followed to schedule irrigation.

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Irrigation scheduling aids have been available to farmers and growers for years, but adoption of these practices has been limited, as indicated by an USDA survey (USDA-NASS, 2002). In addition, variability in soil types, irrigation systems, management practices, and crops indicate that any one monitoring method may not fit all management situations with equal guarantee of benefit (Sanden et al., 2003). A survey conducted in New Mexico indicated that agriculture consumed 85% of available water (Sammis and Mexal, 2005). Forty three percent (43%) of 9,078 farmers responded that they simply looked at the condition of the crop, and this represented the major method of irrigation scheduling. Calendar scheduling was used by 19% of users, soil water feel was used by approximately 16%, and soil water sensing devices were used by approximately 4% of users. Climate- and model-based scheduling aids were only implemented by 0.2 % of users. Low adoption rates of irrigation scheduling aids are caused by high implementation costs, lack of user simplicity, and mistrust of recommendations by water balance models. Although simple in concept, soil water sensors require proper interpretation for accurate irrigation scheduling, which is one reason why sensor-based scheduling has not been widely adopted. Although not an exhaustive listing, the reader is referred to studies by Eldredge et al. (1993), Thomson et al. (1996), Thomson and Ross (1996), Meronuck et al. (1999), Irmak and Haman (2001), and Shock (2003) for discussion of calibration, performance, and irrigation scheduling applications using granular matrix soil water sensors.

Research has been directed at improving acceptability of model-based scheduling aids. The potential benefit would be great if ease of use, transportability, and robustness issues can be addressed. There is not much dispute over the relative superiority of the Penman (1963) method of estimating evapotranspiration (ET) in most situations (Batchelor, 1984). The Food and Agriculture Organization (FAO) Penman-Monteith model requires adjustment to account for crop characteristics and the averaged effects of evaporation from the soil (Allen et al., 1998). To account for crop/soil characteristics, an experimentally determined crop factor, Kc, was adopted (Doorenbos and Pruitt, 1977) and was further enhanced by the introduction of dual crop coefficients. These dual coefficients are a basal crop coefficient representing crop transpiration, Kcb (Wright, 1982), and a soil evaporation coefficient, Ke (Allen et al., 1998). The improved coefficient greatly improved transferability of crop coefficients to other environments, but the coefficient depended on the percentage of time from planting to effective cover, which can vary with plant and root system development (Bausch, 1995). More recent standards for estimating reference ET have been developed with an objective of improving the transferability of crop coefficients (Allen et al., 2005).

To permit wide-area use and more convenient derivation of crop coefficients, Bausch and Neale (1987), Bausch (1995), and Hunsaker et al. (2005) presented concepts by which crop coefficients could be derived by remote sensing. ET estimates made using spectral vegetation indices compared well with those made using standard Kcb-based indices, indicating good potential for the use of remote sensing-based crop coefficients. Bausch (1995) further indicated that a soil-adjusted Kcb improved irrigation timing.

Field devices that integrate environmental effects and measure evaporation can also be used to schedule irrigation. These devices respond to water removal and water addition, like rainfall or irrigation. One meteorologically based device used for irrigation management is the evaporimeter, which can be any evaporation measuring device, such as an atmometer (Broner and Law, 1991) or evaporation pan, whose data can be related to crop water use by applying crop coefficients as are used to modify evapotranspiration models. The World Meteorological Organization (WMO) has recommended that the Class A evaporation pan (as described by Fuchs and Stanhill, 1963) be adopted as the standard instrument for crop water use determination. Smajstrla et al. (2000) presented detailed procedures on using the Class A evaporation pan along with a water accounting method for irrigation scheduling. Empirical crop coefficients (Kpan) that depended on weather factors and pan exposure were detailed. The visual observation of weather conditions and the extent of bare soil or vegetated surface surrounding the pan should be used to choose an appropriate pan coefficient. Standard crop water use coefficients (Kc) are then applied. The merits of using the Class A evaporation pan were discussed by Stanhill (2002), who concluded that the pan may still be the most practical and accurate meteorological method for determining irrigation water requirements. Only environments utilizing automatic weather station networks might benefit more from a data intensive, but accurate, water use model, such as the FAO Penman-Monteith model (Monteith, 1965; Allen et al., 1998).

Simple evaporimeters can be made using inexpensive washtubs. The washtubs are simple, low cost, and can easily be placed in several locations in a sprinkler irrigated field (Westesen and Hanson, 1981). The authors used reference marks on tubs separated by an amount equal to the allowable soil moisture depletion or the net application made by the center pivot (2.5 cm in their example). If heavy rains occurred, the tub was emptied to the top mark. The authors indicated good acceptance by farmers, and tubs were used for several years across Montana.

In a continuing effort to develop simple yet effective irrigation aids, the washtub concept has been expanded one step further. An evaporimeter based on a washtub was designed for easy monitoring from the road, precluding the need for trips into the field or the need for detailed water accounting procedures. The UGA EASY (Evaporation-based Accumulator for Sprinkler-enhanced Yield) evaporation pan was developed at the University of Georgia and consists of a #3 galvanized washtub with a float connected to an adjustable rod that is hinged to allow it to swivel (Fig. 1; Thomas et al., 2002). The rod is connected to a pointer, which indicates crop water status against a back-plate that can be seen from the road. The back-plate has a black line that indicates field capacity and a red line that signals to the observer when to irrigate.

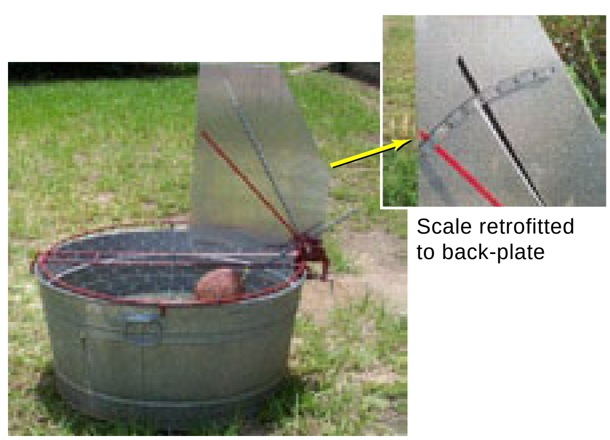

Figure 1. UGA EASY pan irrigation scheduler.

The rod can be adjusted back and forth according to soil/crop combination and period of the season by loosening a setscrew. High frequency irrigation in sand might require high sensitivity (the rod with a shorter travel), while lower frequency irrigation in clay soils might require the rod to be extended. The pan has a hole drilled in the side to permit overflow corresponding with the point of soil saturation.

Harrison and Thomas (2001) detailed guidelines to set up and use the EASY evaporation pan for practical irrigation scheduling and recommended three procedures for setting the pan. First, the position of the float rod should be set based on the water holding capacity of the soil in combination with the rooting depth of the crop. If the allowable amount of available water to be removed from the soil is known, the float rod is set to that amount according to a chart that relates readily available water to float rod position. For sandy soils in Georgia, a setting of 5 (about half the length of the rod) worked well. This setting allowed for the low water holding capacity of a sandy soil and was very responsive to changes in evaporation. Secondly, the use of a screen material covering the pan was specified to limit evaporation based on the crop's actual evapotranspiration (ET). Thirdly, the pan should always be near the top of the plant canopy for consistency of measurements.

Thomas et al. (2004) discussed performance characteristics of the EASY Pan used to schedule irrigation of cotton and peanuts grown in loamy sand soils in southern Georgia. Seasonal water application based on pan recommendations was within 5 mm of application decisions using soil water sensors. Average yields were similar between methods. The use of different screen materials in conjunction with float rod position adjustments was beneficial for scheduling irrigation in well drained loamy sands.

Thomson et al. (2002) presented preliminary data on the use of the EASY pan for cotton planted in a poorly drained Sharkey clay soil. A scale was retrofitted to the pan's back-plate to give a quantitative indication of water level. Soil-water tension (negative potential) was monitored simultaneously at three depths in the soil to provide some indication, other than visual, of crop water status and a relative indication of root activity in the soil zones. The cotton was irrigated according to the field manager's observation of the crop. The EASY Pan was monitored and data were collected but not used for irrigation scheduling. For heavy clay, the float rod was set to full travel (10 on the rod's scale), as recommended by Thomas et al. (2002), with the understanding that float rod adjustments could be made as the season progressed. Screens to limit evaporation were not placed on top of the pan so maximum sensitivity would be achieved. Results indicated an expected response to irrigation, rainfall, and evaporation, but readings from the pan's gauge were offset from the range between the red (irrigate) and black (field capacity) lines. This was partially attributed to the difficulty in specifying field capacity for clay soil when initializing the pan at the beginning of the season. The observed offset can be altered by adjusting the pointer against the back-plate as the season progresses so indications are within the proper range. In the 2002 study, there were few irrigation cycles, so there were few opportunities to correct the pan's calibration during the season. Irrigation was called for by soil water sensors, but the pan's sensitivity (based on travel of the float rod) was too low for irrigation to be called for by the pan. Shortening the rod travel was necessary to increase sensitivity. Thomson et al. (2002) also noticed quality control problems between pans, as some purchased pans read differently on the back-plate for a given float arm position; however, this was not of great concern because calibration procedures (to be described herein) require that the pointer be bent to a set location against the back-plate for early-season initialization.

Based on preliminary experiences with the EASY pan, a need was seen to develop guidelines for accommodating low frequency irrigation in fine soils and adjusting the calibration for temporal increases in crop water use if necessary. Proper scheduling of irrigation using this pan in clays typical of the mid-South could be a challenge, because there are few opportunities to verify pan adjustment during the season because of the few irrigation cycles. The potential payoff could be great, since removal of one irrigation (over standard scheduling by "feel") could save 25% in water and energy over a season that typically sees four irrigations. Another challenge for use of the pan is that the soil's water holding capacity and points of soil saturation and field capacity for early-season pan initialization might be difficult to determine accurately.

The objective of this study was to provide guidelines for setup and use of the UGA EASY evaporation pan for low-frequency sprinkler irrigation of cotton in fine clay soil commonly found in the mid-South of the United States.

MATERIALS AND METHODS

Experiments were conducted at the Application and Production Technology Research Unit (APTRU) Mechanization Farm, which is part of the Jamie Whitten Delta States Research Center, Stoneville, MS. The EASY Pan was installed in a grass lane between two semicircular halves of a field totaling 3 ha (hereafter called field 13) planted in cotton (*Gossypium hirsutum* L.) and irrigated by a single-tower center pivot. This location provided easy access to the pan and good pan visibility. The pan was placed near the starting point for the irrigation operation. Although guidelines presented by Thomas et al. (2002) and Harrison and Thomas (2001) specify placing the pan in the field near the top of the plant canopy, this was not practical in this field, because cotton in this field can typically grow to 150 cm, which would necessitate repositioning the height periodically. Since a goal of the project was to limit the field manager's work, the pan was placed in an open area of the field irrigated by the center pivot. A potential disadvantage, however, was that limited fetch by this placement could alter the evaporation rate compared with that obtained if the pan were unobstructed above the crop.

Stoneville BXN 47 (Stoneville Pedigreed Seed Co.; Memphis, TN) cotton was planted 22 Apr. 2003 (day 112). The predominant soil type in field 13 was a heavy clay in the Sharkey series (very-fine, smectitic, thermic Chromic Epiaquerts), which was relatively uniform throughout the field. This poorly drained soil indicated limited rooting capability for cotton when compared with other soils at the Stoneville Mechanization Farm (Thomson and Fisher, unpublished data). The last time the field was subsoiled was in the fall of 2001.

Pan initialization. Significant rainfall events occurred on days 162 and 168. These rainfall events were used to set initial conditions for the pan by assuming that rainfall events refilled the soil profile. The evaporation pan was filled with water and the pointer was bent so that the scale read 6 on the scale at overflow, corresponding to saturated soil conditions. This setting corresponded to about 5 cm of available water from saturation to field capacity (reading 4 on the scale) in a 23-cm zone of water regulation. The available water was estimated using characterization data for a clay soil in the Sharkey series (USDA-NRCS, 2003; Fig. 2).

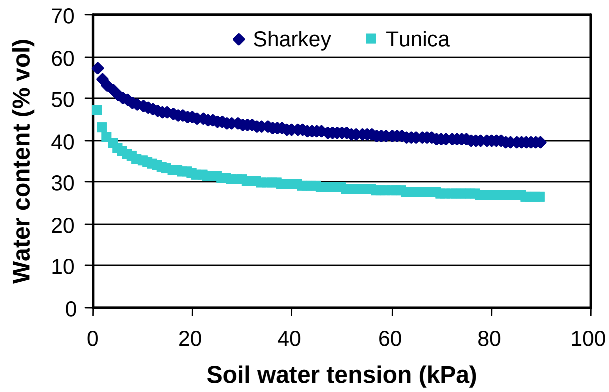

Figure 2. Soil water retention curve derived for a Sharkey clay soil and a Tunica clay soil.

Soil water sensors. Watermark Model 200SS granular matrix soil water sensors (Irrometer Co., Riverside, CA) were installed at the 23-, 46-, and 69-cm depths, equally spaced in four quadrants of the field (Stations 7, 8, 9, and 10). Sensors were read in the morning using the Watermark 30 KTCD-NL meter. Soil temperatures at the 30-cm depth were measured using a thermocouple at the end of a long probe, which was inserted slowly into a guide hole made in the soil. Readings at this single depth were used to compensate Watermark readings at all depths for temperature, using equations presented in Thomson and Armstrong (1987). The single depth for temperature readings was assumed to be adequate for temperature compensation at all depths since soil temperatures do not change appreciably at depths greater than 30 cm. Insects and weeds were controlled using standard practices.

Criteria for irrigation based on readings from soil water sensors. To properly evaluate the pan, criteria for triggering irrigation were established using soil water sensors as the control. A procedure was first developed to derive a weighted soil water tension value from readings of soil water sensors at different depths. For triggering irrigation, a weighted value of 60 kPa was selected based on yield data for cotton grown in the Mississippi Delta (H.C. Pringle, personal communication, 2000). The criteria for irrigation outlined herein can be used with any chosen trigger level, so it is also appropriate for deficit irrigation strategies.

Composite tension values at each sensor station were determined using a weighted average based on an estimate of relative water uptake in each soil zone. Example data to arrive at a composite value are illustrated in Tables 1 and 2. The calculation procedure follows:

1. An approximate water retention curve for the soil (Fig. 2) was obtained by fitting an equation to data for a Sharkey clay presented by USDA-NRCS (2003). Spatial distribution of the soil class was confirmed for field 13 by soil survey (USDA-SCS, 1961). Soil electrical conductivity determinations, using the Veris 3100 Soil EC Mapping System (Veris Technologies; Salina, KS) (Thomson and Hanks, 2004), also confirmed the uniform texture of heavy clay soil within this field in the shallow 30-cm zone.
2. Sensor readings of tension at the 23-, 46-, and 69-cm depths were converted to corresponding water contents using the retention curve.
3. Temporal changes in water content at each depth determined the relative contribution of water uptake. Changes in water content over 6-d periods of drying were determined at each depth. The change in water content at a single depth divided by the total change in water content for all zones was then used to determine an approximate percentage contribution of water uptake at each depth.
4. Percentage contributions of water uptake at each depth were then multiplied by the value for water tension at that depth. These tension results were then added together to obtain a weighted value at each station. Weighted tensions were then averaged across stations to obtain an average value for the field.

Readings were taken from both the pan and soil water sensors during the 2003 cropping season. Pan readings were compared with sensor readings and the results of the evaluations are detailed. Based on results from 2003, evaluations were conducted for 2004 and using data collected from 2002 to develop criteria and procedures for proper setup and use of the pan for irrigation scheduling of cotton in fine soils.

Table 1. Data from day 209 and day 203 showing weighted soil water tension for day 209 (27 July 2004)

Location	Day 209		Day 203		Weighting of water content difference (%)	Weighted composite tension @ day 209 (kPa)
	Tension (kPa)	Volumetric water content (%)[y]	Tension (kPa)	Volumetric water content (%)[y]		
Station 7						
23 cm	65	40.67	18	45.80	81	56
46 cm	19	45.58	15	46.53	15	
69 cm	16	46.27	15	46.53	4	
Station 8						
23 cm	52	41.56	12	47.42	94	49
46 cm	11	47.77	10	48.15	6	
69 cm	13	47.10	13	47.10	0	
Station 9						
23 cm	90	39.36	39	42.71	100	90
46 cm	1	57.36	1	57.36	0	
69 cm	24	44.65	35	43.14	0[z]	
Station 10						
23 cm	38	42.81	16	46.27	79	34
46 cm	20	45.38	17	46.03	15	
69 cm	15	46.53	14	46.81	6	
Ave. soil water tension						57

[y] Retention curve equation used for Sharkey clay was Q = -4*ln(bars)+38.942. This was fit to data from the USDA-NRCS (2003) soil curve.

[z] This value was zeroed because the 69-cm sensor indicated wetting, not drying over the 6-d period.

Table 2. Data from day 222 and day 216 showing weighted soil water tension for day 222 (9 Aug. 2004)

Location	Day 222		Day 216		Weighting of water content difference (%)	Weighted composite tension @ day 222 (kPa)
	Tension (kPa)	Volumetric water content (%)[y]	Tension (kPa)	Volumetric water content (%)[y]		
Station 7						
23 cm	90	39.36	57	41.19	27	78
46 cm	77	39.99	23	44.82	70	
69 cm	18	45.80	17	46.03	3	
Station 8						
23 cm	73	40.20	31	43.63	100	73
46 cm	11	47.77	12	47.42	0[z]	
69 cm	13	47.10	13	47.10	0	
Station 9						
23 cm	109	38.60	76	40.04	12	27
46 cm	16	46.27	1	57.36	88	
69 cm	22	45.00	32	43.50	0[z]	
Station 10						
23 cm	80	39.83	45	42.14	39	64
46 cm	56	41.26	24	44.65	57	
69 cm	16	46.27	15	46.53	4	
Ave. soil water tension						61

[y] The retention curve equation used for Sharkey clay was Q = -4* ln(bars)+38.942. This was fit to data from the USDA-NRCS (2003) soil curve.

[z] These values were zeroed because the 46- or 69-cm sensor indicated wetting, not drying over the 6-d period

RESULTS

2003 evaluation. Using soil water tension data, weighted tension values of 60 kPa (trigger values) were achieved on day 191 (79 DAP, 10 July 2003), day 209 (97 DAP, 28 July 2003), and day 224 (112 DAP, 12 Aug. 2003) (Fig. 3). The scale for the evaporation pan initially read 1.75 on day 191. The float rod (Fig. 1) was adjusted inward (to the right) until the pointer corresponded to the red “irrigation” line (reading of 0.75 on the scale, Table 3) after which irrigation was used to supply 5 cm of water (Fig. 4a). The 5 cm of irrigation was a customary application chosen by the field manager for all fields. Irrigation was supplemented by a small rainfall event, which brought total water replenishment to 7 cm. The added water set the pan to the baseline field capacity reading of 4 on the back-plate scale (Fig. 1). Even after initial adjustment, subsequent calls for irrigation by soil water sensors (trigger level = 60 kPa) did not correspond to red-line readings for the pan on day 209 (97 DAP) or day 224 (112 DAP), as illustrated in Table 3 and Fig. 4a.

Based on these observations, another scale change because of higher demand for water would have brought the pan in line with sensor readings for days 209 and 224. If the float rod was moved inward until the scale read 0.75 on day 209 (one scale division lower), the curve illustrated in Fig. 4b would have resulted. This adjustment would have also been enough for the pan to signal irrigation on day 224. Two adjustments (the initial one at day 191, and another at day 209) would have signaled irrigation of cotton grown in this Sharkey clay soil for the 2003 season.

Potential irrigation savings. According to the field manager’s recommendation, 5 cm of irrigation was applied to the field on days 201 (89 DAP) and 212 (100 DAP) (Fig. 4a), although field sensors did not indicate irrigation was required on day 201. Irrigation was permitted, however, to demonstrate potential improvements to the field manager’s recommendation using data from both the pan and soil water sensors. If the pan or sensors had been used to schedule irrigation, a single irrigation could have been applied at day 209 (97 DAP) and the next irrigation at day 212 (100 DAP) could have been eliminated.

Table 3. EASY Pan scale readings from 2003 before adjustment corresponding to composite soil water tension level of 60 kPa used to trigger irrigation

Day	Days after planting	Actual pan scale reading	Irrigation trigger level (scale reading)
191	79	0.75	0.75
209	97	1.75	0.75
224	112	2.00	0.75

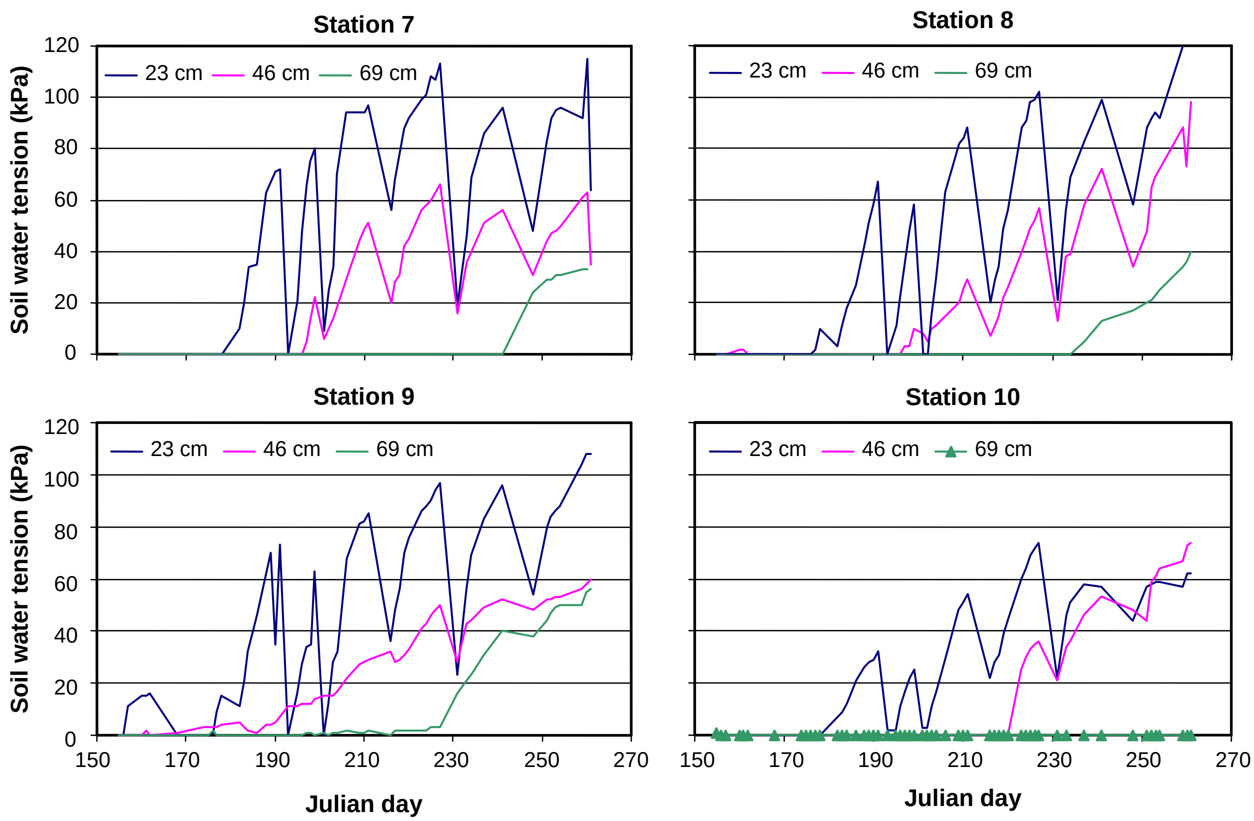

Figure 3. Temporal readings of soil water retention (negative potential) at four field stations of field 13 tested in 2003.

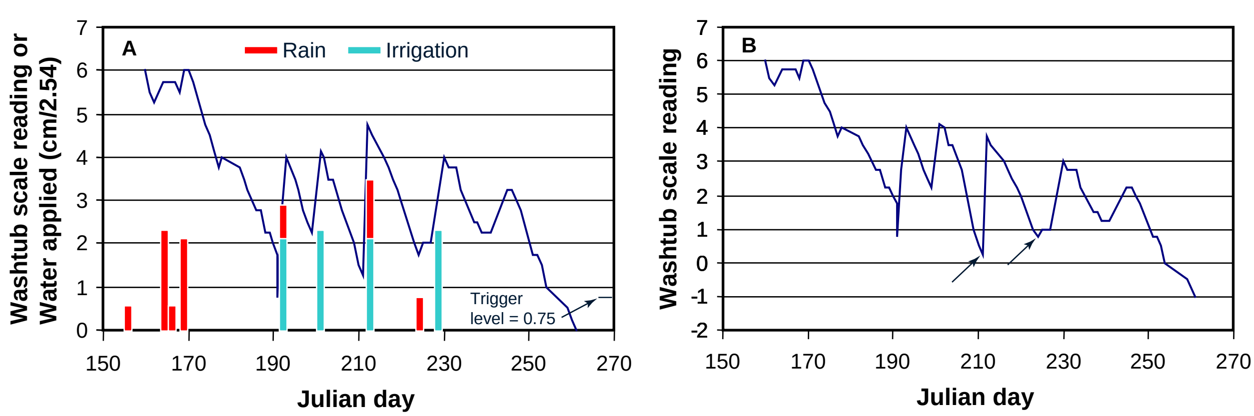

Figure 4. A)Temporal readings from evaporation pan from the 2003 test. B) Readings that would have been obtained if the float rod were adjusted at day 209 (97 day after planting; 28 July 2003). Lower scale readings indicate higher water deficit.

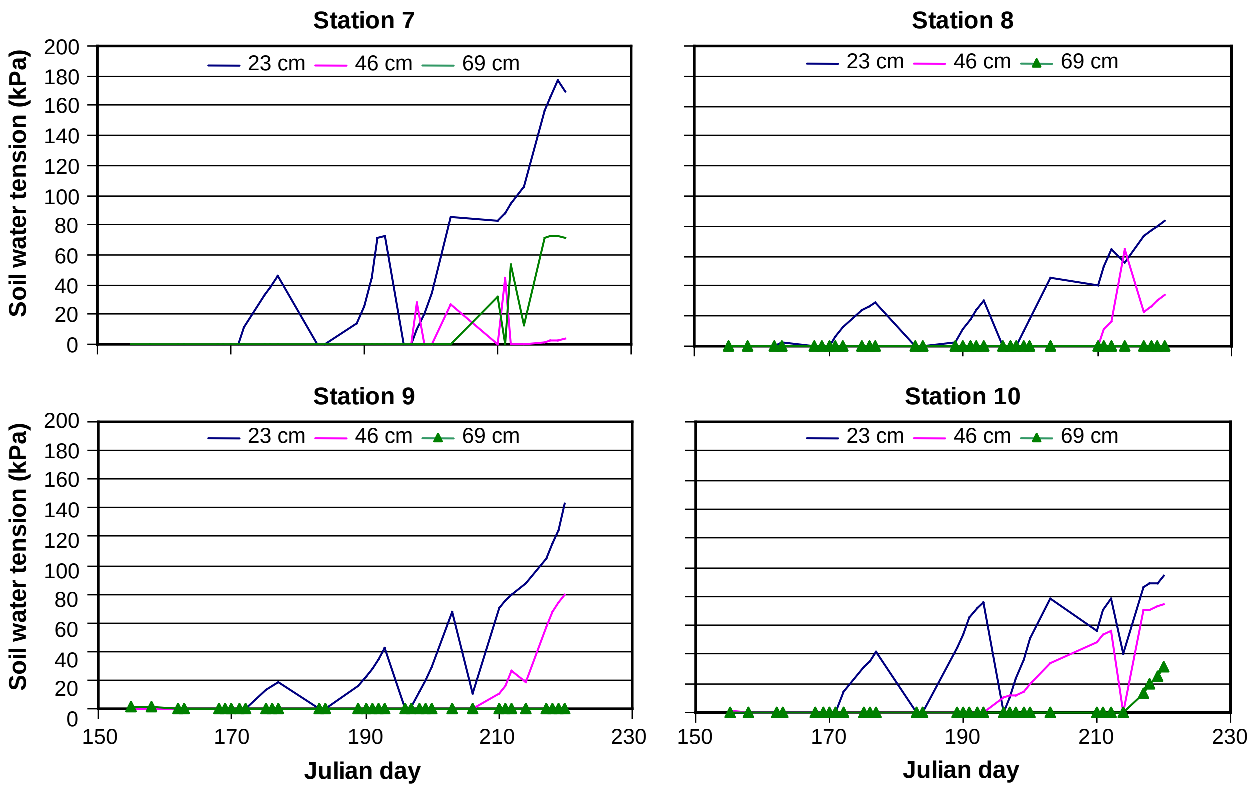

Figure 5. Temporal readings of soil water tension (negative potential) at four field stations of field 13 tested in 2002.

Independent verification of pan adjustments. Use of the pan and crop criteria for within season adjustments were evaluated for 2002 and 2004 to account for weather conditions that are variable from one year to the next. Soil water sensors were placed at the same field locations as the 2003 study for both years. Stoneville BXN 47 (Stoneville Pedigreed Seed Co.) was planted on day 113 (23 Apr. 2002) and Stoneville 4892 BR was planted on day 113 (22 Apr. 2004).

To determine its operational characteristics, the pan was first evaluated in 2002 (Thomson et al., 2002). A full set of evaporation and soil water data obtained during 2002 were used to support pan adjustment criteria obtained in 2003.

In 2002, water use was recorded with no adjustments to the pan after initial setup. Individual readings from soil water sensors are illustrated in Fig. 5. To evaluate the pan for its utility in scheduling irrigation using data from 2002, readings from the study of Thomson et al. (2002) were offset downward to correspond with scale readings from the 2003 study (Fig. 6). This offset was determined by observing the first day irrigation was required, based on a weighted tension reading greater than or equal to 60 kPa. A trigger level of 60 kPa occurred at day 193 (80 DAP, 12 July 2002), and the scale reading at that date was offset to a value of 0.75, corresponding to the red "irrigate" line on the pan. From this new baseline reading of 0.75, trigger values determined by the pan could be compared with tension values obtained from soil water sensors on subsequent days.

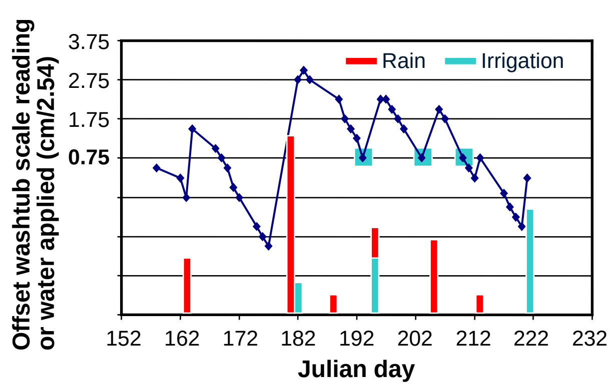

Figure 6. Data from the evaporation pan and irrigation and rainfall amounts for the study conducted in 2002. Readings from the study of Thomson et al. (2002) were offset downward to correspond with scale readings from the 2003 study.

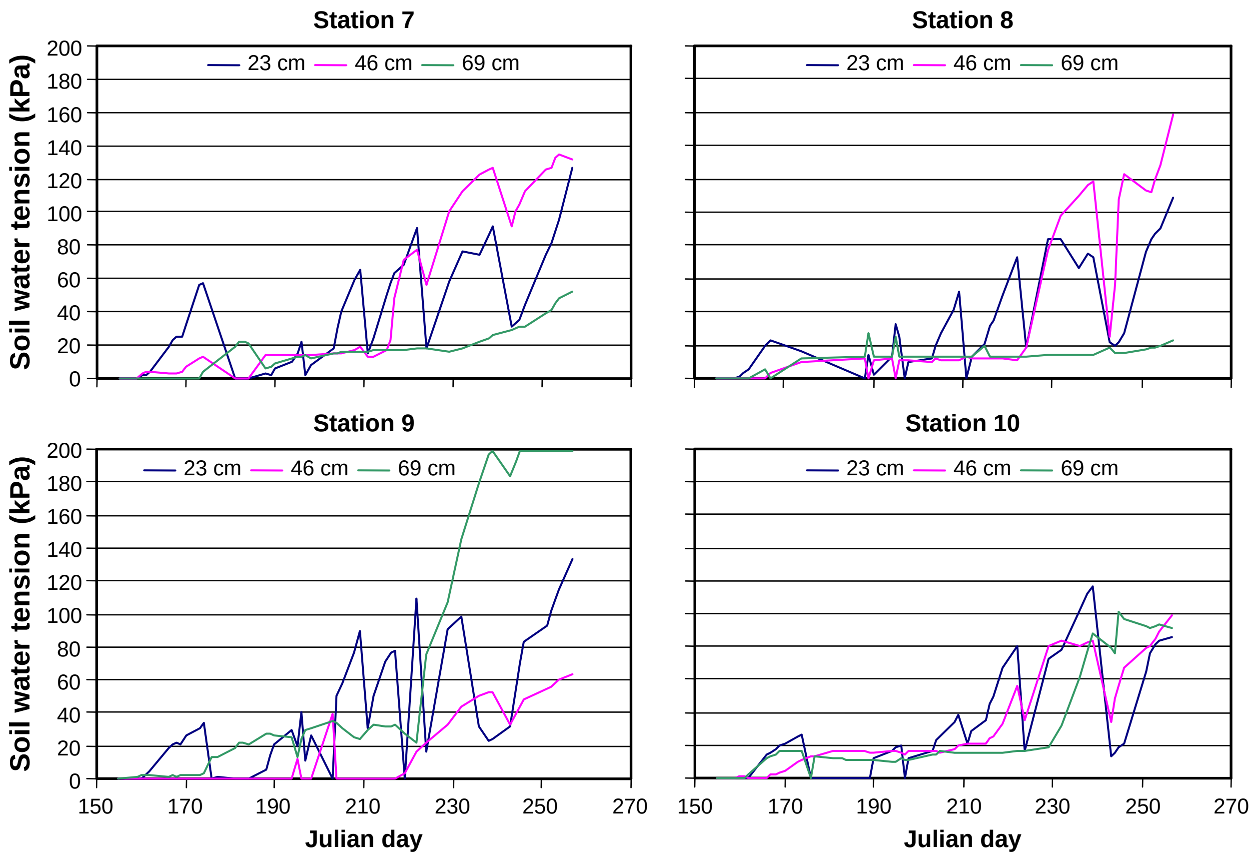

Figure 7. Temporal readings of soil water tension (negative potential) at four field stations of field 13 tested in 2004.

Signals for irrigation occurred at day 203 (90 DAP) and day 210 (97 DAP) as highlighted in Fig. 6. Weighted tension values were then calculated for those days across the four stations before water replenishment. The calculated composite values were 59 and 62 kPa for 90 DAP and 97 DAP. Both values were very close to the set trigger level of 60 kPa. The single rod adjustment at day 193 seemed to be adequate through day 210, as verified by the weighted tension value for the field. About 5 cm of rain replenished the zone for day 203, but the field manager allowed the field to dry between day 210 (97 DAP) and day 220 (107 DAP). It appears that the irrigation of 6.5 cm on day 220 should have been made 10 d earlier (on day 210) instead.

In 2004, the pan was set up using knowledge gained from its use in the 2003 season. Individual readings from soil water sensors are illustrated in Fig. 7. Pan readings were recorded and compared with weighted tension values as before, and no adjustments were made to the float rod during the season to account for increased water use. Irrigation was practiced according to field manager-defined schedules as in the other years.

It was easy to specify a point of soil saturation for initial setup in 2004, since there were numerous high intensity rain events early in the season (Fig. 8). On day 197 (84 DAP), 4 cm of irrigation was applied, although neither the pan (scale reading = 3, Fig. 8) nor the weighted tension value (26 kPa) indicated that irrigation was needed. The field was also irrigated on day 210 (97 DAP). The pan scale reading was 2 (indicating no need for irrigation), but the weighted tension value was 57 kPa (Table 1). The

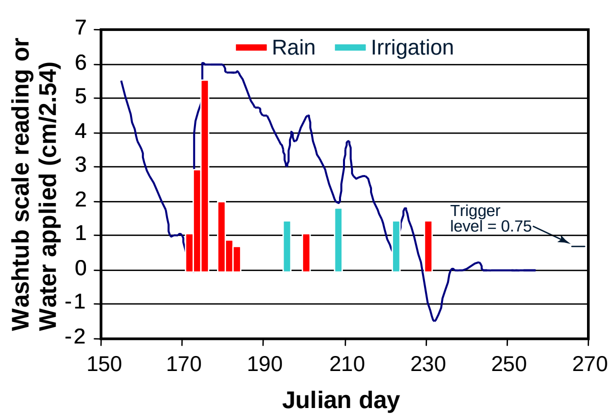

Figure 8. Data from the evaporation pan and irrigation and rainfall amounts for the study conducted in 2004.

weighted tension value supported the field manager's assessment that irrigation was needed soon, but the pan's scale reading did not support that assessment. If the pan's float rod had been adjusted so the scale read one division lower (as recommended for 2003), recommendations would have fallen in line with what sensors were indicating. The new scale reading would have been 1, which indicated irrigation was needed soon (close to the 0.75 trigger point).

The final irrigation event occurred on day 227 (114 DAP), and this corresponded to a reading of 0.5 on the pan scale (slightly below the 0.75 trigger point). The weighted tension reading on day 226 was calculated as 61 kPa, about equal to the sensor-derived trigger level. It should be noted that if the one-division scale offset was applied on day 210, the need for irrigation would have been signaled by the pan on day 219 (106 DAP) not day 226. The corresponding weighted tension value for the field on day 219 was 47 kPa, slightly less than the trigger point of 60 kPa.

DISCUSSION

The UGA EASY evaporation pan with one additional adjustment provided good results for the 2003 season. An adjustment was also recommended for the 2004 cropping season to compensate for increased temporal crop water demand. Both adjustments were made 28 d after white bloom. The pan was successfully evaluated using data already collected from part of the 2002 cropping season, but the need for a second adjustment could not be verified. A single rod adjustment made at the beginning of the season was not enough to signal irrigation on day 209 for the 2003 crop but was suitable at day 210 for the 2002 crop. Visual observation indicated a less vigorous crop for the 2002 season, so the best time to adjust the pan for a second time was probably delayed. Subsequent analysis of crop stage data for 2002 showed that white bloom occurred on about day 192 (79 DAP), about 10 d after the day white bloom was recorded for 2003.

For 2004, it appears that the first irrigation (day 197, 85 DAP) could have been eliminated, as neither the pan nor soil water sensors indicated irrigation was needed. It is interesting to note that the only criterion for the field manager's decision to irrigate was that the crop seemed to have been "lagging" and needed water. Errors in subjective decision-making like this further strengthen the case for using an irrigation scheduling device such as the EASY pan.

The need for a second pan adjustment was not as solid for the 2004 season as the 2003 season because of inconsistencies (already described herein) between sensor readings for days 210 and 226. Yield comparisons between the two years indicated reduced overall lint yield for 2004, which correlated well with field observations of lower vigor. Average lint yield for the field, obtained from yield monitor data file, was 764 kg/ha (1.42 bale/a) for 2003 and 678 kg/ha (1.26 bale/a) for 2004.

The final irrigation event occurred on day 222 (9 Aug. 2004, 110 DAP). If an offset of one scale division had been applied on day 210, the need for irrigation would have been signaled by the pan a few days earlier on day 219 (107 DAP). On that day, a weighted tension value of 47 kPa was calculated, which was slightly below the sensor-based trigger level of 60 kPa. Although a pan adjustment at day 210 would have brought pan readings in line with soil water sensor readings, there is some evidence that the additional adjustment might not have been required at that time, since crop growth was delayed because of the numerous heavy rains early in the season.

The results could have been influenced by the method used to calculate weighted tensions and water retention estimates based on the published soil curve. If actual soil water retention curves were available from soil samples obtained on-site, those data should be used instead of the published retention curve(s). Data in Fig. 7 indicates that sensors at deeper depths began to respond later in the season, as would be expected. A different weighting formula could account for this activity with an even greater bias towards water uptake at the deeper depths. This would provide a more conservative irrigation schedule. Yield response and cotton quality differences might also be quantified assuming other variables can be tightly controlled.

A method using DD60 heat units for tracking crop stage (Miller et al., 2002) was considered for determining the time to reposition the float rod for 2003, factoring in growth differences because of temperature. Accumulation of heat units for the 'standard' cotton plant is published by the Mississippi State University Extension Service (Silva, 2006). The 2004 data indicated problems with use of heat units for tracking growth stages. Crop development was delayed (observationally) by heavy rains early in the season, although accumulated DD60s indicated later stages of growth. Delay in growth was further evidenced by lysimeter data that recorded actual water use on another field. Lysimeter data showed peak water use was delayed by 35 d when compared with the published curve for mid-South cotton (unpublished data, 2005).

Placement of the evaporation pan in the field could prove difficult, because a location should be chosen that gets full irrigation coverage but is not obstructed from view. As has been indicated, periodically raising the pan to maintain it at canopy height is probably not feasible in practice. Even if it were feasible, the pan could be out of reach for servicing or observation from the road. As their testing progressed, Thomas et al. (2004) also indicated a decreased need for raising the evaporation device if alleyways were available. In this study, the pan was placed in a wide lane between field halves, so this study had an advantage in field placement. One point to consider when placing the pan in any position that is not at the top of the canopy is the potential for differences in evaporation rate between installations. Inadequate fetch and tight placement close to a maturing crop would invariably record a lower evaporation rate than say, a pan placed at the top of the canopy or in a lane with adequate fetch near a short crop. Evaporation rate would be influenced by differences in wind exposure. Smajstrla et al. (2000) specify pan coefficients (Kpan) for the National Weather Service Class A evaporation pan to account for varying wind exposure, upwind distance to green crop or bare soil, relative humidity, and wind speed.

For this study, one irrigation could have been delayed and another eliminated for 2003 (a 25% water savings), and the first irrigation could have been eliminated for 2004 (a 33% water savings) if pan recommendations had been followed for scheduling irrigation. This exemplifies the importance that a scheduling aid, such as the EASY pan, can have for timing of low frequency irrigation.

Based on our experiences using the EASY pan for cotton grown in fine soils, the following recommendations are indicated for the pan's proper setup and use:

1. The pan's float rod should first be set to an initial point using guidelines presented by Thomas et al. (2002). A chart in that publication relating float rod position to available water indicates a rod setting at Position 9 for 7.5 cm of available water (as determined from the soil water retention curve for a Sharkey Clay, Fig. 2). Position 9 corresponds to a setting of 3 cm (one division) inward from the end of the rod.
2. A scale should be placed on the pan's back-plate (Fig. 1) 33 cm from the pointer's pivot point. A depth ruler should also be placed in the pan or carried to the field for depth measurements. The scale should have major graduations 2.5 cm (1.0 in) apart and minor ticks placed 0.6 cm (0.25 in) apart. Although the scale will not be readable from the road, the scale can serve to help calibrate the pan. The pan's scale should then be calibrated (at least roughly) against water depth at the chosen initial float rod setting (step 1, above). The difference in scale reading should be noted as a known amount of water (as indicated by the depth ruler) is applied. This will be the approximate 'depth to scale' factor. If a more precise calibration over many points is desired, a relationship like that illustrated in Fig. 9 can be obtained by filling the pan progressively to overflow, and noting readings from both the scale and depth ruler.

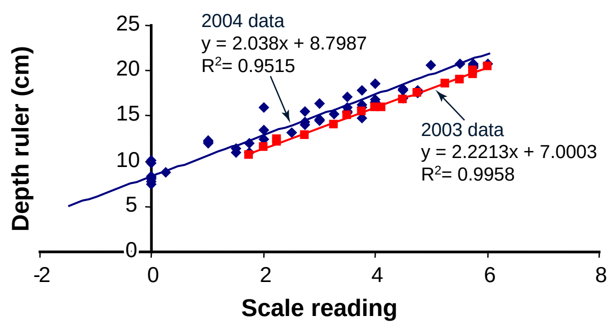

Figure 9. Comparison of readings from the back-plate of the evaporation pan and from a ruler measuring the water depth in the pan for the 2003 and 2004 tests.

3. For physical calibration to the predominant soil, the pan should be filled to overflow. The amount of water held between saturation and field capacity in the first 23 cm of soil should be estimated for the field soil using soil water retention curves (USDA-NRCS, 2003), and the scale pointer should be bent at the bottom to read above the black line by the number of divisions corresponding to that amount of water using the pan's calibration curve (as derived in Step 2, above). If lab-derived soil water retention curves are available, those should be used instead of published curves.
4. After a saturating rain or irrigation early in the season, the pan should be completely full to overflow for initialization. For fine soils, rainfall amounts known to saturate the zone of water regulation are sometimes difficult to verify. The user should use experience to determine if rainfall was sufficient

for saturation of a shallow rooted zone (no more than the upper 23 cm). Granular matrix sensors or soil water content measuring devices can be used to help identify this point of saturation. As an additional check or if a rainfall of sufficient quantity is not imminent, it is also suggested that granular matrix soil water sensors be used to determine the first irrigation trigger point for early decision-making after which the pan can be used stand-alone. The sensors should be placed 23 cm deep for cotton at enough stations to represent varying soil and topography. Early in the season (up to about 65 DAP), sprinkler irrigation could simply be based on readings from one or more soil water sensors placed at a 23-cm depth. When these sensors indicate the trigger level has been reached (60 kPa in our case), the pointer should indicate at the red line (0.75 on the scale). If it does not, the float rod should be moved in or out so that the pointer reads on the line.

5. The float rod should not require repositioning until the cotton crop is well underway. Based on data from 2003 and 2004, the rod should be repositioned about 28 d after white bloom until the pointer reads one scale division lower against the back-plate (Fig 1). It is realized that the crop's growth curve can vary from season to season, so adjustment based on this observable crop stage takes this into account.

CONCLUSIONS

Irrigation events in the mid-South are often infrequent and number between two to five over the entire growing season with the rainfall patterns typical of the area. Cotton grown at the APTRU Mechanization Farm is typically irrigated with 4 to 6 cm of water per application. Since there are so few water applications, strategic timing of irrigation events is critical. For this study, one irrigation was not needed over each of two seasons the pan was used. This irrigation represented a high proportion of total water applied in both seasons. Water application of 5 cm per irrigation was considered to be sufficient to supplement rainfall and to supply the crop's needs based on wetted-response readings from soil water sensors.

Guidelines presented for use of the UGA EASY pan for cotton in clay soils depend on identification of the point of soil saturation for early season pan initialization. If that point is difficult to identify early, soil water sensors can be used to set the pan's red-line setting (signal to irrigate) as the soil dries. For two years the pan was used, an adjustment to increase the pan's sensitivity was necessary to account for increased crop water use about 28 d after white bloom. Strategies presented here should be usable along with those presented by Thomas et al. (2002) for setup of the EASY Pan for other crops and soils. In some cases, use of screen materials to limit evaporation may be useful along with adjustment of the pan's float rod (Thomas et al., 2002). Both rod travel adjustment and screens are simply sensitivity adjustments for the pan. A within-season pan adjustment was necessary to account for increased crop water demand, much like a crop stage-dependent coefficient. At least one within-season adjustment would probably be necessary for all crop/soil combinations. Recommendations made herein for within-season adjustment of the pan based on crop stage can serve as a good starting point for cotton. If simple replenishment of available soil water is not the only desired criteria for use of the pan, an independent monitoring method might be beneficial the first time the pan is used in the field. A single soil water potential sensing device could be installed about 23 cm deep at enough spatial locations to represent differences in soil type or topography. In this experiment, the upper 23 cm of soil accounted for approximately 88% of water uptake differences mid-season as registered by soil water sensors at four spatial locations (Table 1). Crop-specific recommendations on soil water potential would be used to provide the irrigation trigger level. The sensors can be used as a check early in the season and should be monitored more closely mid-season to assist in verifying the effect of mid-season pan adjustments on irrigation decisions.

DISCLAIMER

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply approval of the product to the exclusion of others that may be available.

ACKNOWLEDGEMENTS

The authors would like to thank Lawson Melton, Richard J. Horton, Lindsey Sheffield, Matthew Bates, and Jamesetta Lipsey for data acquisition; J. Roger Bright for setup, calibration, and maintenance of the evaporation pans and sensors; Ashley Harris for processing and preliminary data analysis.

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