Comparison of irrigation scheduling methods in the humid Mid-South

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ABSTRACT

The appropriate scheduling of irrigations can result in more efficient use of water and energy resources, improved yields, and reductions in runoff and off-site pollution. Fields planted to cotton in the lower Mississippi Delta region of the humid Mid-South were irrigated based on four scheduling methods: 1) the original Arkansas Irrigation Scheduler, 2) an updated (2008) Arkansas Irrigation Scheduler, 3) a spreadsheet with an FAO-56 ET-water-balance model, and 4) a soil-moisture sensor-based method. The different methods did provide guidance on when to irrigate, but assumptions built into the models led to differences in schedules under certain conditions. Violating the assumptions led to under-irrigation in some cases, and reductions in yield. Yields were affected by tillage practices, with yields slightly higher under minimum-tillage conditions. Soil type also affected the potential usefulness of any scheduling method, with irrigation treatments in a clay soil resulting in yields lower than those from non-irrigated treatments.

INTRODUCTION

The appropriate scheduling of irrigations can result in more efficient use of water and energy resources, improved yields, and reductions in runoff and off-site pollution. Irrigation scheduling is common in arid and semi-arid regions, where irrigation is required due to inadequate rainfall. In the humid Mid-South region of the US, where rainfall is more frequent, the use of irrigation is increasing. Irrigation is used as a supplemental source of water for those times when rainfall is insufficient to meet crop-water needs.

A variety of scheduling methods exist and range from simple, soil-feel and visual methods to more scientific methods. Computer-based models often use weather data and a water-balance approach to keep track of water incoming (rainfall, irrigation) and outgoing (evapotranspiration) to determine when soil-water resources become depleted. Sensor-based systems monitor conditions in the field, and give an indication of the soil-water status directly.

Tillage practices and soil conditions can interact with crop growth and irrigation-water requirements. Field conditions affect the timely application of irrigation water and can impact crop yield and water-use efficiency.

Objectives

The objectives of the study were to test the impact of four irrigation scheduling methods under differing soil and tillage conditions on final harvest yield. The four scheduling methods included the original Arkansas Irrigation Scheduler, an updated (2008) Arkansas Irrigation Scheduler, an FAO-56 ET-water balance method, and a soil-moisture sensor-based method. Tillage treatments included conventional and minimum-tillage preparations.

EXPERIMENTAL SETUP

The study was conducted at the Jamie Whitten Delta States Research Center, Stoneville, Mississippi USA, during the 2008 growing season. The research center is located at approximately 33.4° North latitude and 90.9° West longitude, at an elevation of 125 feet above sea level.

Three fields, designated AP2-1, AP2-2, and MF4, were used in the study. Each field was prepared for raised-bed, furrow-irrigated production on a 38-inch row spacing. Soil types in fields AP2-1 and AP2-2 varied across the fields, and consisted of Tunica clay, Dundee silty clay loam, and Dundee very fine sandy loam. The soil in field MF4 was more uniform and consisted mainly of Tunica clay. The fields were subdivided into small plots, each 8 rows wide. Fields AP2-1 and AP2-2 measured 780 ft long and had 15 plots each. Field MF4 measured 450 ft long and contained 20 plots.

Fields were prepared under two tillage systems; conventional tillage in fields AP2-1 and MF4, and conservation, or minimum tillage in field AP2-2. Conventional tillage consisted of those practices in common use by producers in the Mid-South region. Following harvest in the fall, stalks were shredded, fields were lightly disked, and the rows were bedded up and left to settle during the winter. The following spring, the rows were rehipped and then knocked down to form a stable seed bed, and the field was planted.

Minimum-tillage is a practice which is becoming increasingly common as producers look to reduce input labor and costs. In the fall, stalks were shredded, and a roller with busters was pulled across the field to form shallow furrows for drainage and irrigation. In the spring, the fields were planted, and if needed, the roller/busters were used again clean out the furrows to help facilitate irrigations.

The fields were surface irrigated by pumping groundwater from a nearby well through flexible polypipe containing adjustable plastic gates. Each field was supplied through a separate length of polypipe, and was instrumented with a propeller-type flow meter. Adjustable plastic gates allowed the plots in each treatment to be irrigated as needed: gates were open when a plot was to be irrigated and closed when no irrigation was required.

Scheduling methods

Four scheduling treatments, and a non-irrigated treatment, were replicated in each field. Fields AP2-1 and AP2-2 had three replicate plots per treatment, and field MF4 had four plots per treatment. The four irrigation scheduling methods consisted of 1) the original Arkansas Irrigation Scheduler, 2) an updated (2008) Arkansas Irrigation Scheduler, 3) an FAO-56 ET-water balance method, and 4) a soil-moisture sensor-based method.

The Arkansas Irrigation Scheduler is a computer model developed by the University of Arkansas Cooperative Extension Service (Ferguson et al., 2000). The program uses a water-balance approach to calculate a daily soil-water deficit. The user enters general field, soil, crop, and irrigation-system information into the program at the beginning of the season to configure the model. Daily air temperature, precipitation, and irrigation data are then entered throughout the growing season. The program calculates a daily reference ET using an empirical temperature-based method, and a built-in crop coefficient function is applied to estimate crop ET. The daily soil-water deficit is determined by adding the crop ET to the previous day's deficit and subtracting any rainfall that occurred. When the deficit reaches a critical, allowable deficit, established by the user, an irrigation is needed.

In 2008, an updated version of the Arkansas Irrigation Scheduler was released (Vories et al., 2005). The main enhancement over the original version was the ability of the user to enter daily reference ET values rather than temperature values. This allowed the user to bypass the empirical temperature-ET relationship of the original program and enter ET values determined locally, from an evaporation pan or using more complete weather data and a more sophisticated ET model. Other features (crop coefficient functions, water-balance routine, irrigation criteria, etc.) from the original program were retained. The ability to enter reference ET values is an improvement, however, the crop coefficient functions need further attention. Crop coefficients are unique to the reference-ET method used in their development and may not be appropriate if applied to a different reference-ET method.

A third water-balance model was developed which used a standard computer spreadsheet to record daily weather data, calculate daily reference- and crop-ET values, and determine daily soil-water deficits. The FAO-56 Penman-Monteith reference-ET model (Allen et al., 1998) and a locally-developed crop coefficient function (Fisher, 2004 and additional unpublished data) were used to estimate crop ET. Precipitation and irrigation amounts measured at each field completed the water-balance data. Daily cumulative soil-water deficits were calculated, with critical, allowable deficit values estimated from the NRCS Soil Survey for the area (SCS, 1961).

In the soil-moisture sensor treatments, sensors were installed in each plot and connected to dataloggers. Granular matrix sensors (Watermark SS-200, Irrometer Co., Riverside, CA) were installed at three depths, 6-, 12-, and 24-in below the soil surface, at two locations in each plot. Sensor measurements were collected and stored automatically at two-hour intervals using battery-powered dataloggers (Fisher, 2007). Sensor data were monitored to determine when soil moisture status reached a critical value, at which time an irrigation was needed.

Scheduling procedures

Irrigations of the plots under each scheduling treatment in the three fields were scheduled independently of each other. Daily weather and precipitation data were input to each of the computer models, and daily soil-water deficits were calculated. Data from the soil-moisture sensors were downloaded periodically and input to a spreadsheet in order to monitor daily soil-water status. For each treatment, when the critical allowable-deficit level was reached, an irrigation was scheduled.

Critical allowable-deficit levels were determined for each scheduling method. Both Arkansas Irrigation

Schedulers offered guidance on selecting the allowable limit based on soil, crop, and irrigation system information. The level selected for this study was 2.5 in of water. For the water-balance spreadsheet model, information provided in the SCS soil survey suggested an allowable deficit of 2.5 in also. For the soil-moisture sensor plots, a level of –60 cbar was chosen.

Upon reaching the allowable limit, an irrigation was scheduled. The adjustable plastic gates in each plot to be irrigated were opened, and water was applied to replenish the deficit. The amount of water applied was measured with flowmeters and converted to an equivalent depth for each plot. The water balances for each computer model were then updated to reflect the irrigation event.

At the end of the season, the plots were harvested individually and total plot yields were measured. The center four rows of each plot were harvested with a four-row mechanical spindle harvester. The cotton was then transferred to a boll buggy equipped with electronic loadcells, and the total weight of the cotton was measured and recorded. Yield from the two rows on either side of the center four rows was not measured: conditions in adjoining plots may have affected these edge rows, resulting in crop growth and yield inconsistent with that due to the plot treatment.

RESULTS AND DISCUSSION

Weather data from the Mississippi State University weather station at Stoneville were collected for input to the irrigation scheduling models. Weather data were input to the RefET Reference Evapotranspiration Calculator software (Allen, 2002) to estimate daily reference ET using the FAO-56 method. These reference ET values were input to the 2008 Arkansas Irrigation Scheduler and the spreadsheet water-balance model. Maximum daily air temperature was input to the original Arkansas Irrigation Scheduler.

Rainfall

Precipitation amounts were measured with raingages located at each of the fields. Rainfall is highly variable spatially in the Mid-South, and can vary greatly over a short distance. To illustrate this, rainfall amounts measured during May 2008 in field MF4 and at the weather station, which are approximately 3 miles apart, are shown in Table 1. Rainfall measured at the weather station was over 2 inches greater than that measured in field MF4.

The difference in rainfall amounts could have a significant affect on water-balance calculations and irrigation schedules. If the weather-station data had been used, the irrigation schedule may have indicated that the soil-water deficit was less than the allowable amount, while in fact, the soil may have been much drier. If rainfall is highly variable, locally measured data must be used to give an accurate account of conditions in the field.

Irrigation schedulers

The four scheduling methods were run throughout the growing season. The weather-based models were updated daily, and the soil-moisture sensor data were collected weekly and input to a spreadsheet for analysis. When the soil-water deficit reached the allowable limit for each method, an irrigation was scheduled. Each irrigation was planned to occur the following day, but on several occasions other field operations delayed the irrigation for up to several days.

Resulting irrigation schedules for each of the four scheduling methods for field MF4 are shown in Figure 1. Each schedule shows the daily soil-water deficit, allowable deficit, rainfall amounts, and irrigation events that occurred during the growing season. Three of the methods resulted in three irrigations being scheduled in the middle of the season. One method, the updated Arkansas Irrigation Scheduler, called for only two irrigations. In the latter part of the season, rainfall was sufficient so that no further irrigations were required.

Daily reference ET values calculated by the FAO-56-based method were lower than those from the temperature-based routine in the original Arkansas model. The same crop coefficient functions were used in both Arkansas models, and the lower ET values resulted in the updated Arkansas model (Figure 1b) calling for one less irrigation than the original model (Figure 1a). The spreadsheet water-balance model (Figure 1c), which also used the FAO-56 reference ET values, used a different crop coefficient, and resulted in

Table 1. Precipitation measured during May 2008 with an in-field raingage and at the weather station.

Day	Raingage readings	
	field MF4 in	weather station in
2	0.43	0.63
7	0.16	0.24
8	0.04	0.12
13	0.35	0.43
14	0.91	1.85
15	0.39	0.51
22	0.28	0.67
24	0.31	0.31
27	1.89	2.12
total	**4.76**	**6.88**

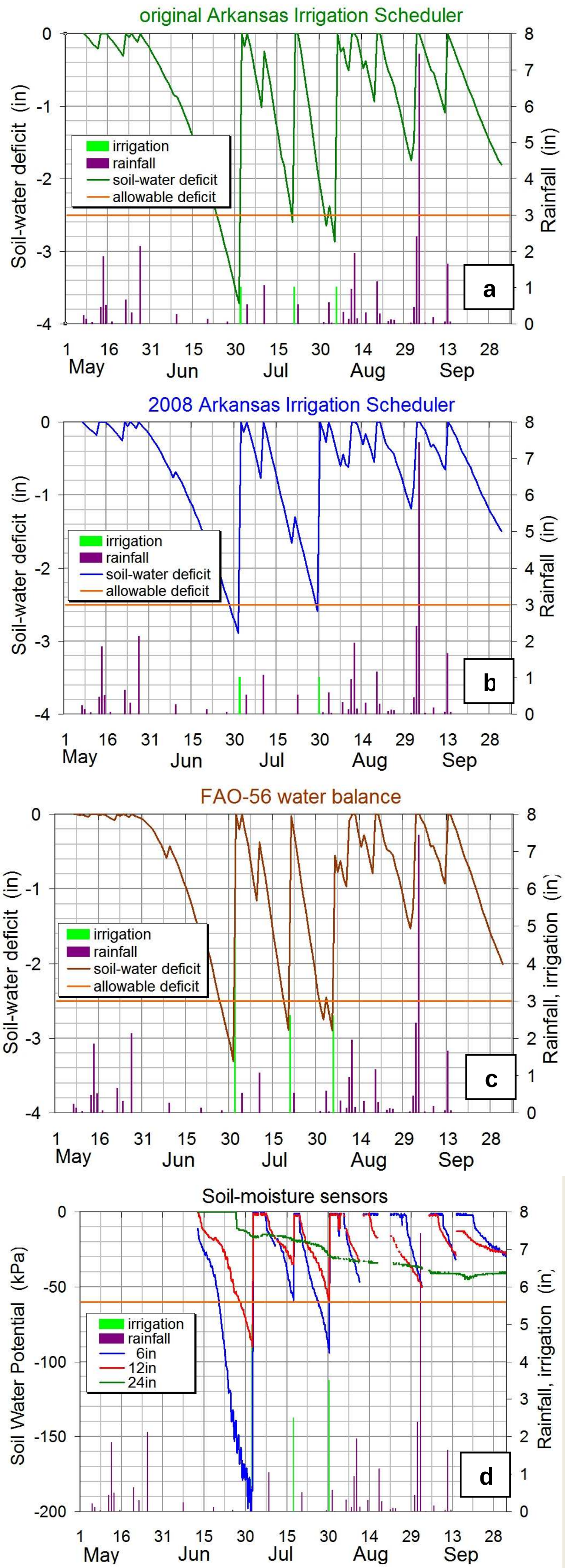

Figure 1. Irrigation schedules from each of the four scheduling methods for field MF4.

a seasonal schedule similar to the temperature-based model (Figure 1a).

The soil-moisture sensors measured actual conditions in the field and did not rely on any calculations or additional data collection. The resulting schedule (Figure 1d) agreed well with the other models.

One of the main assumptions in the Arkansas Irrigation Scheduler models deals with what happens after an irrigation. The Arkansas models assume that when an irrigation event occurs, the irrigation is sufficient to replenish the soil-water deficit, and the soil-water deficit is reset to zero. The amount of irrigation water applied is not entered into the scheduling program, but rather only an indication that an irrigation occurred. The graphs in Figures 1a and 1b reflect this by showing a vertical bar with length 1 when an irrigation occurred. In the other schedulers (Figures 1c and 1d), the actual amount of irrigation water applied is shown.

Irrigation schedules for fields AP2-1 and AP2-2 were similar but highlighted the Arkansas schedulers' idea that every irrigation was sufficient to reset the soil-water deficit to zero. Infiltration problems in these fields made it difficult to apply adequate amounts of

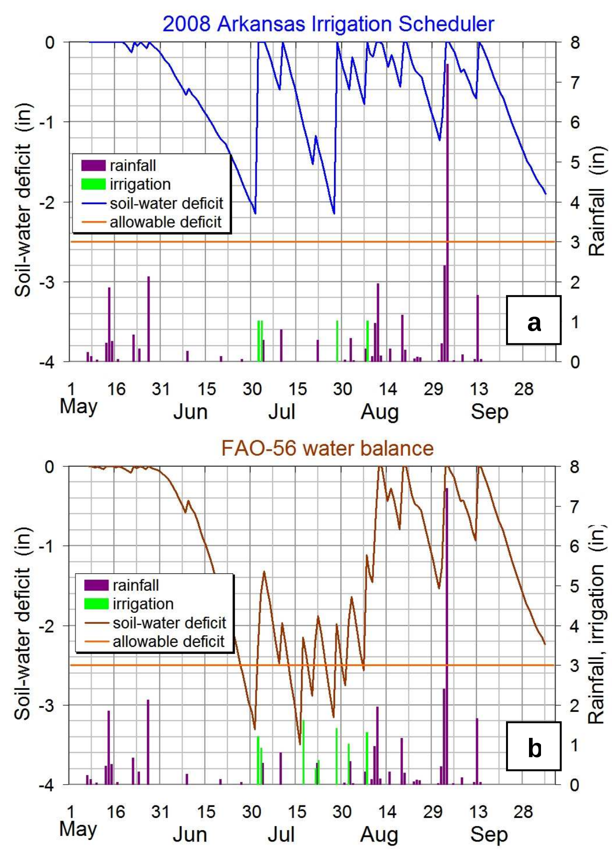

Figure 2. Irrigation schedules for two scheduling methods for field AP2-1.

water during an irrigation. Based on flowmeter readings, equivalent depths of irrigation ranged from 0.4 to 1.4 in before irrigations were ceased in order to prevent excessive runoff. In some cases, water was able to be applied for two consecutive days, but total water applied was usually less than 1.5 in.

In Figure 2, schedules are shown for two methods for field AP2-1. In Figure 2a, the Arkansas scheduler shows three irrigation events: two irrigations were called for based on the soil-water deficit values approaching the allowable limit, but a third irrigation was made to try to apply additional water to make up for the inadequate second irrigation. If flowmeter readings had not been available, each irrigation would have been assumed to be adequate and only two irrigations would have been made.

The FAO-56 water-balance method in Figure 2b shows six irrigations. This method used the actual amount of water applied form each irrigation to update the soil-water deficit rather than resetting the deficit to zero. This method shows that the irrigations were not sufficient, resulting in many more irrigation events being needed. This method also resulted in more water being applied, further indicating that the amount of water applied using the Arkansas scheduler was insufficient.

Table 2. Amount of irrigation water, total water, and yield for each treatment.

Treatment	Irrig water applied in	Yield ba/ac
AP2-1 (conventional tillage)		
Original Arkansas Scheduler	5.4	1.46
2008 Arkansas Scheduler	4.8	1.43
FAO-56 water balance	8.4	1.67
Soil-moisture sensors	7.0	1.56
Non-irrigated		0.95
AP2-2 (minimum tillage)		
Original Arkansas Scheduler	5.7	1.56
2008 Arkansas Scheduler	4.9	1.49
FAO-56 water balance	8.4	1.72
Soil-moisture sensors	6.9	1.73
Non-irrigated		1.23
MF4 (conventional tillage)		
original Arkansas Scheduler	10.1	1.69
2008 Arkansas Scheduler	8.5	1.62
FAO-56 water balance	10.1	1.77
Soil-moisture sensors	11.0	1.63
Non-irrigated		1.82

Yield

Yields from the replicate plots in each treatment were measured, averaged, and then converted to yield on an areal basis. Cotton yield from each plot in each of the fields is shown in Figure 3. Average yield for each scheduling method is listed in Table 2. Also listed in Table 2 are the amounts of irrigation water applied for each scheduling treatment.

Yield differences were observed among the four irrigation scheduling treatments and the non-irrigated treatment in each field. An analysis-of-variance (ANOVA) procedure was run on the plot data shown in Figure 3 for each field (results not shown), which

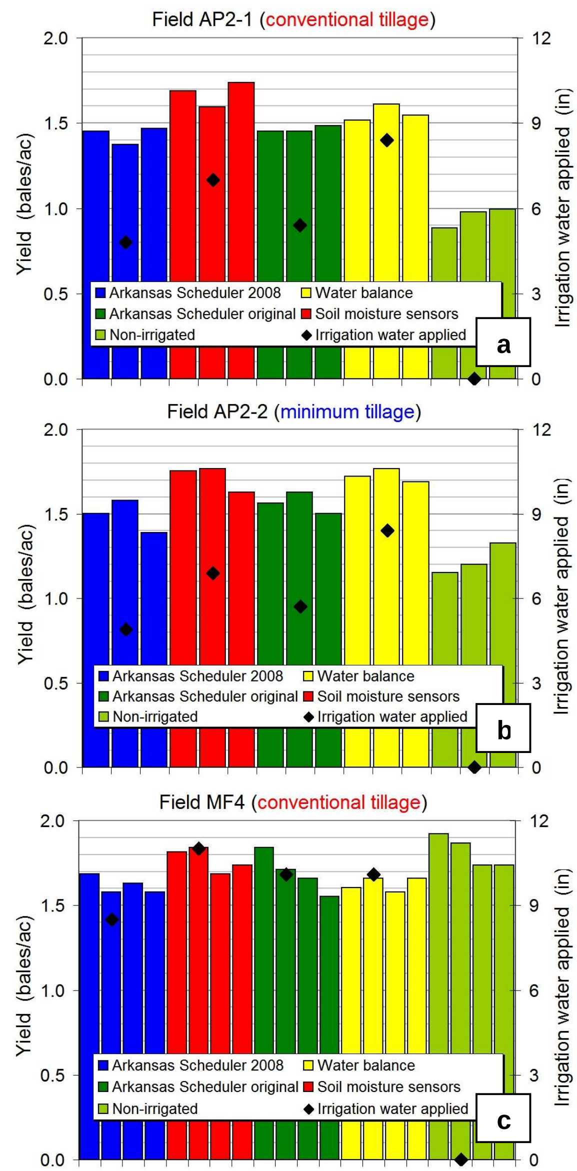

Figure 3. Cotton yield from each plot in each field.

indicated that there were significant differences in yield among the scheduling treatments. The differences in yield were not consistent among the different fields, however, suggesting that no particular scheduling method outperformed the others in terms of yield.
In fields AP2-1 and AP2-2, yields correlated with the amount of irrigation water applied, with higher yields resulting from more water applied. The non-irrigated treatments yielded the lowest, and yields increased as applied water increased. The FAO-56 water-balance and soil-moisture sensor methods returned the highest yields since those treatments also received the most irrigation water. In these fields, where infiltration problems resulted in irrigations which did not completely replenish the soil-water deficits, these two scheduling methods maintained a more accurate account of field conditions than did the Arkansas schedulers.

In field MF4, however, the non-irrigated treatment returned the highest yields. In this case, soil type may have been the determining factor. The clayey soil had sufficient soil-water resources throughout the season, and the irrigations added excess water which affected crop growth and depressed yield. Under the weather conditions experienced this season, and on this type of soil, irrigation was unnecessary and no scheduling method would have improved yields.

Fields AP2-1 and AP2-2 were also part of another study examining the effects of tillage practice on cotton yield. The fields were adjacent to each other and had similar soils, with field AP2-1 under conventional tillage and AP2-2 under minimum tillage conditions. Under each of the irrigation scheduling treatments, yields under minimum-tillage conditions were higher than those under conventional tillage. Yield increases ranged from 3 to 10% in the irrigated treatments, and were 29% higher in the non-irrigated plots.

CONCLUSIONS

Irrigation scheduling is an important tool for meeting the irrigation-water requirements of a crop. Three computer-based scheduling models and a soil-sensor-based method were used to schedule irrigations in several fields throughout the growing season. The four methods proved fairly simple and easy to use, and provided guidance on determining when to irrigate.

While the computer-based models used weather data from a weather station located several miles away from the fields being irrigated, it was important that rainfall be measured at the field. Rainfall is an important component in the water-balance models, and needs to accurately reflect field conditions.

One of the main assumptions of the Arkansas Irrigation Schedulers is that each irrigation event is sufficient to fully replenish the soil-water deficit, resetting the deficit to zero. In cases of insufficient irrigation water being applied, the Arkansas schedulers would still reset the deficit to zero but the actual soil-water deficit would be greater than that. This could result in the following irrigation being indicated later than needed, and the actual soil-water deficit becoming much greater than the allowable limit. This could be avoided by measuring the amount of water applied with a flowmeter to ensure that the irrigation was adequate.

Another alternative would be to use a water-balance method which allowed input of the measured depth of water applied. This would allow a more complete accounting of the water-balance components, and help maintain an accurate estimate of the soil-water deficit. To avoid the need to input any weather data or rely on the construction and assumptions of a computer model, soil-moisture sensors provide measurements of the actual soil-water conditions in the field.

Soil-type interacted with irrigation scheduling and yield in that some soils do not respond to irrigation. Irrigation under certain soils conditions may not be appropriate at all, and yield depression could result.

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.

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