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A model to define operational irrigation frequency for maximum yield of crops*[1]/

AGUSTIN A. MILLAR**, ELIANE N. CHOUDHURY***

Resumo

Descreve-se um modelo para definir a frequencia operacional de irrigação para máxima produção das culturas. As informações básicas usadas no modelo são respostas da planta às condições de umidade no solo, características de retenção e movimento da água no solo, evapotranspiração e demanda atmosférica.

Apresentam-se os resultados da aplicação do modelo nas culturas de tomate e feijão num solo franco arenoso. Discute-se o uso da informação mundial da relação entre rendimento das culturas e potencial matricial de água no solo.

Introduction

One of the most challenging problems facing irrigated agriculture is that of improving the on-farm water management.

For an efficient water management it is necessary to know adequately some basic data that characterize the irrigation method under operating conditions. Besides information on soil water retention and conducting properties, evapotranspiration and crop yield response to irrigation, and evaporative demand must be properly known. The final goal always deals with defining a criteria to guide irrigation scheduling which will favor optimum crop yields and efficient water use.

Several methods based on soil, plant and evaporative measurements have been described to establish irrigation frequency of crops (6, 10). Except for the plant water indicators, most methods do not take into account the crop yield response to irrigation.

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** Ph.D., Irrigation Specialist, IICA, P.O. Box 04-0381, Brasília D. F. Brazil.

*** Researcher, CPATSA/EMBRAPA, P.O. Box 23, Petrolina, PE. Brazil.

The most common way to schedule irrigation is using the water balance of the soil profile. Lewin (12) used a water balance for the top 90 cm of the soil profile with inputs from rainfall and irrigation, drainage of any water in excess of field capacity, and a linear relationship between evapotranspiration and storage. He accounted for potential evapotranspiration and a crop factor by letting the coefficients have different values for each month of the growing season. He further assumed that the decrease in yield of winter wheat should be related to the number of days when soil water potential was less than − 1.2 bars. Similar stress days concepts have been used in many other studies. Lewin (12) found a correlation of − 0,864 between calculated number of stress days and percentage of potential yield.

Fischbach and Somerahlader (5) developed a method for scheduling irrigation with the primary objective of gradually depleting the available soil water during the growing season. They estimated evapotranspiration on the basis of weather records and crop coefficients, using Penman equation for potential evapotranspiration (19).

Water is the production complementary factor that most frequently limits crop yield. In general, most crops respond to variable conditons of soil water. In literature, there exist a sizable volume of experimental results dealing with irrigation effects on crop yield (6, 17, 20). This information is usually given in terms of soil suction levels for obtaining maximum yields. These results, though useful, do not provide elements for quantitative decisions which would allow a choice of a real production level according to the climate, crop, soil and irrigation method conditions and management possibilities.

Millar (14) presented an analysis of world data of soil moisture level-yield experiments which allow a quantitative definition of the yield reduction at soil water potentials beyond optimum conditions. As a conclusion of Millar's work it is apparent that high frequency irrigation goes a long way towards meeting the conflicting requirements of maintaining a high soil water potential to attain maximum yields. This also is the prospect offered by Rawlins and Raats (16). The prior conditions could only be met through drip, trickle, and from solid-set to traveling sprinkler systems. Due to operation and water distribution problems, high-frequency principles become unfeasible under surface irrigation conditions.

This paper deals with a model to define irrigation management to obtain maximum operational crop yield under conditions of surface and high-frequency irrigation systems.

Materials and methods

1. Model description and components

The model uses climate, soil, crop and irrigation management information as inputs (Figure 1).

a. Climate Component

Crop evapotranspiration (ET) is the climate input of the model. ET is defined as a function of soil matric potential of the effective rooting zone of crop, ET = ET (ψ). When this information is not available, ET can be obtained using crop coefficients and pan evaporation data (7).

b. Soil Components

Water Retention – The relationship between the volumetric content (θ) and the soil matric potential (ψ), $\psi = a\theta^{-b}$, becomes one of the most important inputs since ET and crop yield are defined as a function of soil matric potential.

Water Conducting Properties – There are two soil water transmission properties that are essential, the capillary conductivity (k) as a function of volumetric water content, $k = c \exp(d\theta)$, and the drainage rate (D), at the bottom of the root zone, as a function of the water storage (L) in the above soil profile, $D = r \exp(sL)$. Both properties are related through Darcy's Law, $D = -k\ (dH/dZ)$, where dH/dZ is the hydraulic gradient. Both parameters should be obtained under yield conditions using standard methods (2, 8).

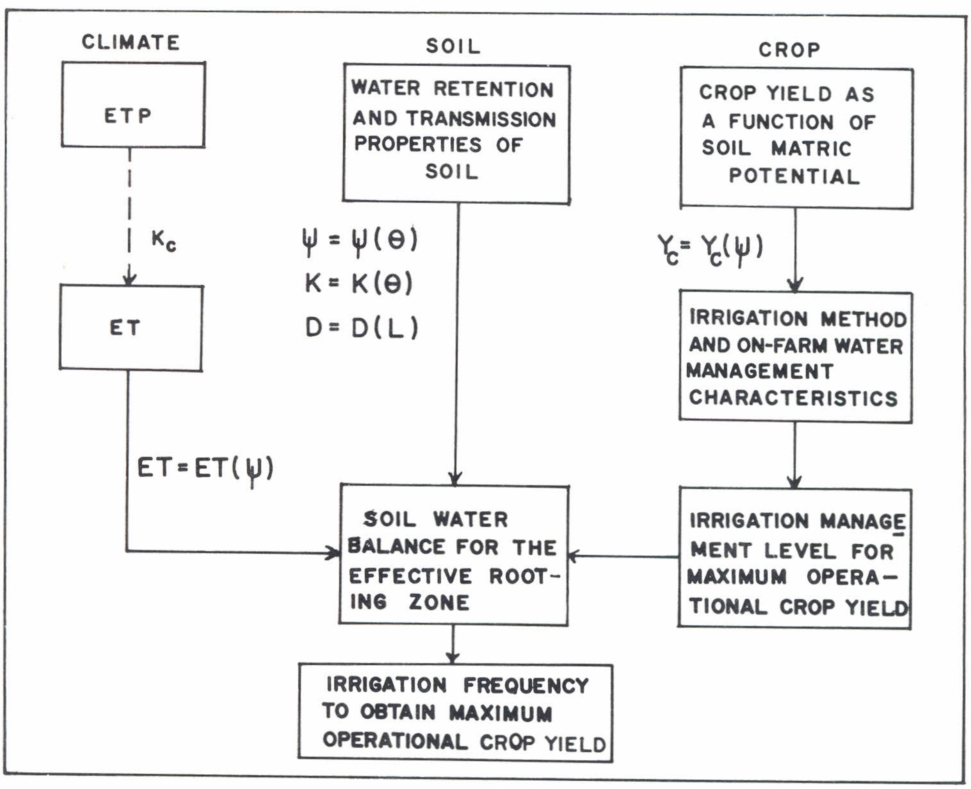

Fig. 1. Climate, soil and crop components of the MOF model.

The use of water storage to define the drainage rate at the bottom of the rooting zone works properly in coarse and medium textured soils as shown by Black **et al.** (1, 2). For heavy soils the drainage rate must be defined as a function of existing moisture conditions at the bottom of the root zone.

c. **Crop Component**

Crop yield as a function of soil matric potential is the essential relationship. This information becomes available through water trial experiments and can be inferred from world data as used by Millar (14).

The relationship is used in the model to define the best water management level in terms of soil matric potential to obtain maximum crop yield under the irrigation method and operational characteristics.

2. **Model Sequence and outputs**

Soil water balance for the effective rooting zone is run starting with soil water storage depth at field capacity level. The sequence of the model is shown in Figure 2. The operational irrigation frequency for maximum crop yield is obtained by superimposing a minimum attainable soil matric potential (ψ) which is a function of crop response, irrigation method and management characteristics.

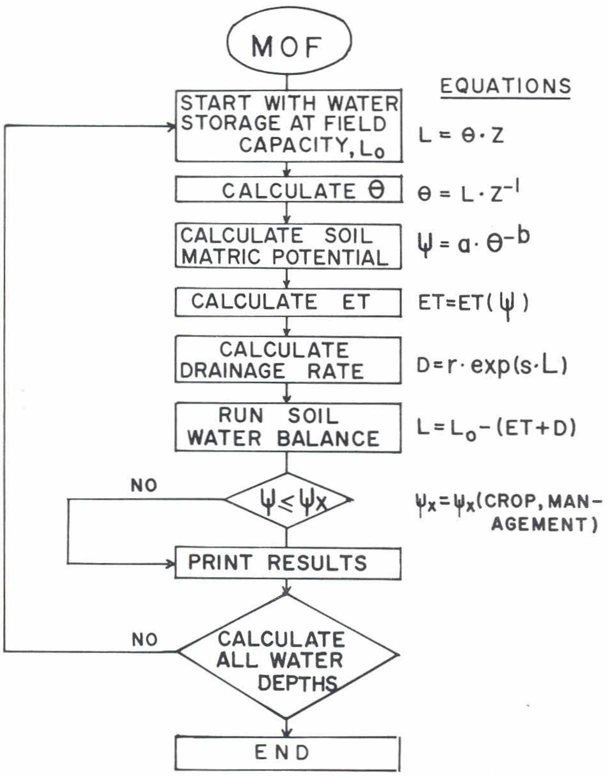

Fig. 2. Sequence of the MOF model.

3. **Basic Data**

The data used to test the model were collected through several studies conducted at the Bebedouro Experimental Station at the Research Center for Semi-Arid Tropics (CPATSA) in Petrolina, State of Pernambuco, Brazil.

Experimental data for tomatoes and beans collected in a sandy loam soil (oxisol unit 37BB) primarily were used to test the model. Figure 3 shows the soil water retention curve and Figure 4 shows the capillary conductivity as a function of soil water content for different soil layers. Figure 5 shows the drainage rate at different depths of soil profile as a function of water storage. All soil water retention and conducting properties data used in the model are being published by Choudhury and Millar (4).

Evapotranspiration data for the tomatoes as a function of soil matric potential (Figure 6) published by Millar **et al.** (15) were used in the model. The evapotranspiration of beans corresponds to data being published by Silva **et al.** (18). Figure 6 also includes crop coefficient as a function of soil matric potential, but these data were not included in the model since $ET = ET(\psi)$ was available.

Figure 7 shows the relationship between relative yield and soil matric potential for tomatoes and beans. These relationships were published by Choudhury **et al.** (3) and Magalhães and Millar (13).

The water management characteristics for surface irrigation systems (furrow method) were taken from the Bebedouro Irrigation Project managed by the Irrigation Development Agency for the San Francisco Valley (CODEVASF).

Results and discussion

Figure 8 shows graphically the results obtained by application of the MOF model to data of tomatoes and beans in an oxisol. From Figure 8, the irrigation frequency can be defined in terms of a minimum (more negative) soil matric potential which must be fixed using Figure 7, for the operational management characteristics.

In general, under surface irrigation conditions crops can only achieve 80 to 90% of potential production due to the fact that irrigation management can not be achieved at high soil water potential.

In tomatoes, for example, irrigation must be managed at −2.4 bar soil matric potential in the effective rooting zone to obtain 80% of the potential production, and at −1.6 bar for 90% of potential

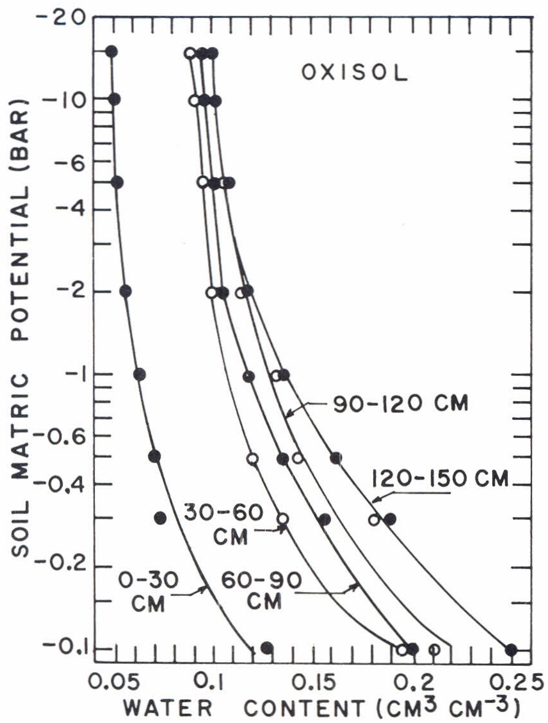

Fig. 3. Water retention curves for different layers of an oxisol.

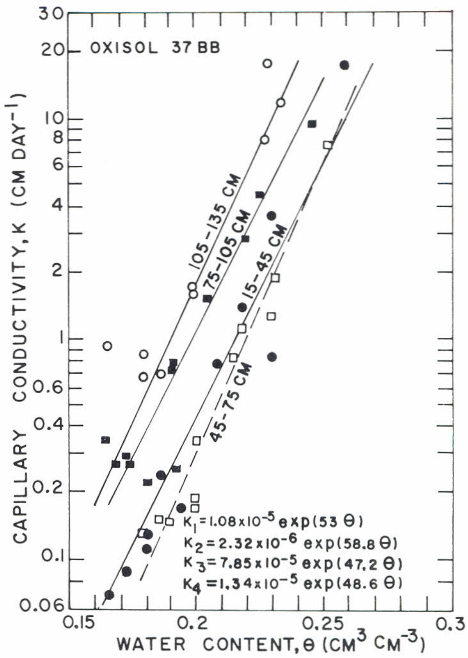

Fig. 4. Capillary conductivity of an oxisol as a function of water content.

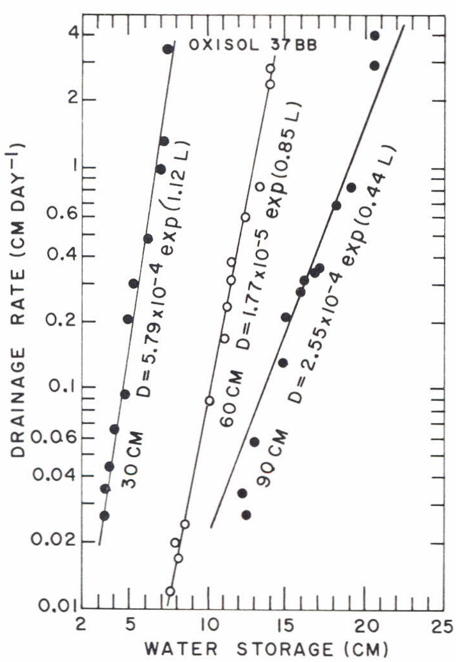

Fig. 5. Drainage rate of an oxisol as a function of water storage depth.

production (Figure 7). These management levels correspond to 7 and 6.5 days irrigation frequencies (Figure 8) and become the operational irrigation frequencies defined by the model. For beans, Figure 7 shows that 80 and 90% of potential production are obtained under irrigation management of –1.7 and –0.75 bar soil matric potentials, respectively. These values correspond to operational irrigation frequencies of 8 and 7.2 days, respectively.

For tomatoes, the soil water balance was run using evapotranspiration as a function of soil matric potential and an average constant value indicated by dots and circles, respectively (Figure 8). There is no clear difference between data points, which would allow use of a constant ET value, as was done for beans (Figure 8).

The levels for operational irrigation management in terms of soil matric potential for other crops can be defined from relationship obtained from application of world data. This has been done by Millar (14) and a summary of his findings are presented in Table 1. The indicated soil matric potential values were obtained from the smooth curves plotted through the experimental results.

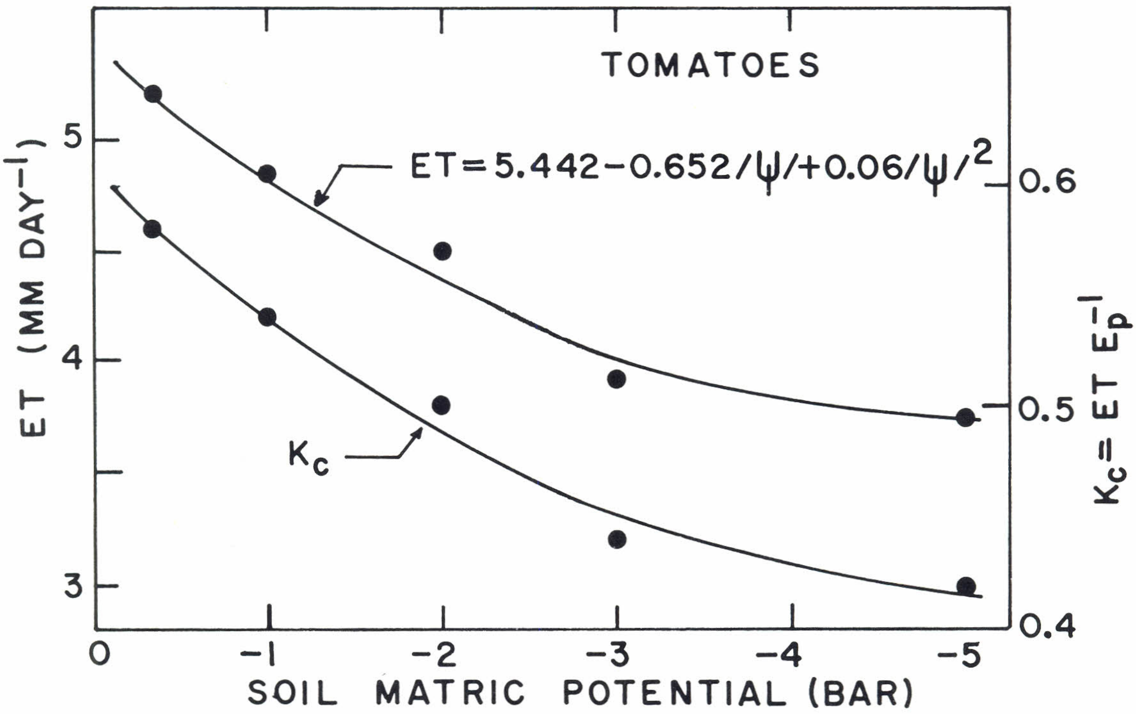

Fig. 6. Evapotranspiration of tomatoes as a function of soil matric potential of the effective root zone.

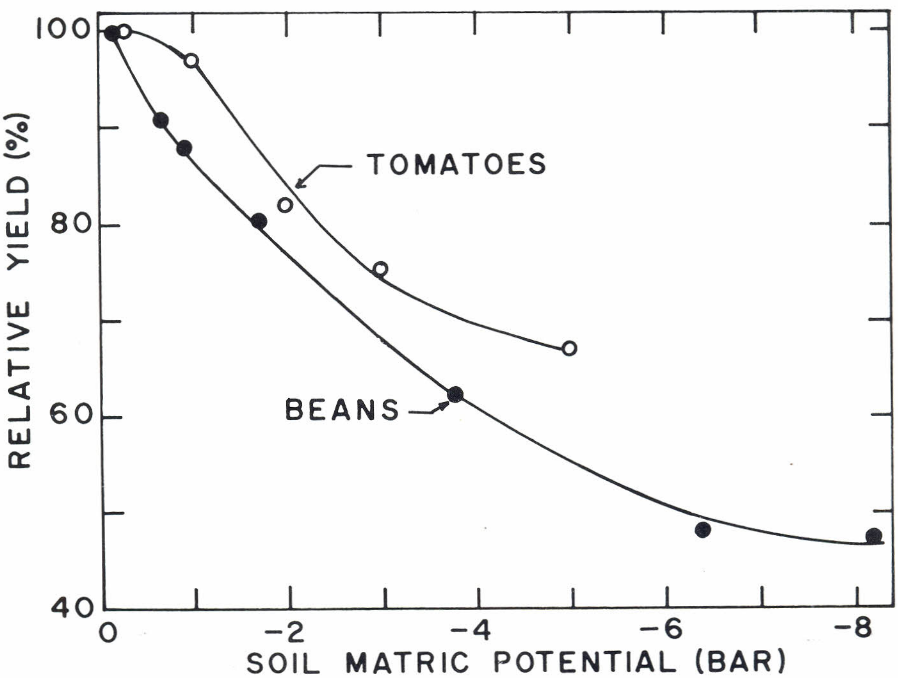

Fig. 7. Relative yields of tomatoes and beans as a function of soil matric potential.

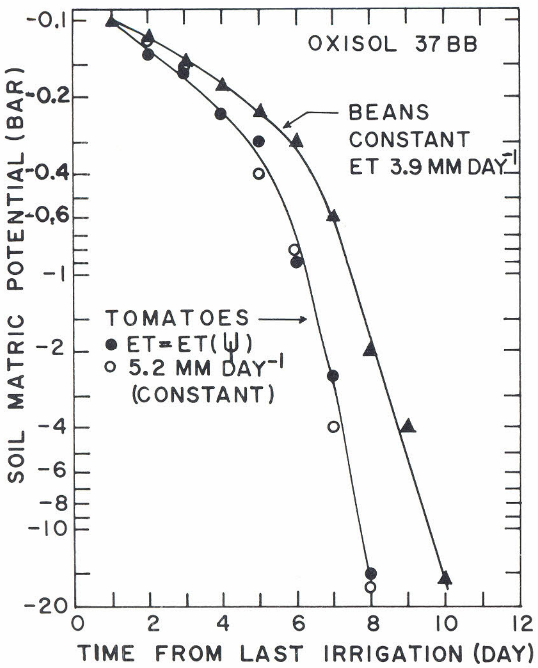

Fig. 8. Irrigation frequency of tomatoes and beans as a function of soil matric potential and crop evapotranspiration.

Many alternatives exist to scheduling irrigation (6, 9, 10, 11). In some areas, irrigation is set up on rotation schedules with constant intervals and either constant or variable amounts, but generally disregarding annual climatic variations and crop response to irrigation management.

As stated by Jensen **et al.** (10), the potential for better irrigation water management has increased substantially due to better water control and measurement facilities, improved system design criteria, more reliable methods for estimating evapotranspiration, increased knowledge of crop response to soil moisture levels, better knowledge and estimation of water conducting properties of soil, and commercially available soil moisture instrumentation for timing irrigations.

The model presented in this paper uses much of the available knowledge, and principally takes into account the crop yield response to water regimes. It can be used in high frequency systems as well as in surface irrigation where on-farm water management and operation conditions are beyond from optimal levels. It also indicates the type of research information that must be produced for efficient irrigation management.

Table 1. Yield levels for different crops when managed at irrigation levels indicated in terms of soil matric potential as obtained by Millar (14).

Crop	Yield level (%)					
	Potential	90	80	70	60	50
	Soil		matric	potential		(bar)
Cereal						
Wheat (Barley)	−0.50	−1.75	−3.2	−4.6	− 6.3	−8.5
Corn	−0.50	−0.90	−1.6	−2.4	− 3.4	−4.9
Horticulture						
Onions	−0.50	−1.6	−2.1	−2.9	− 3.7	−5.0
Potatoes	−0.25	−0.65	−1.1	−1.6	− 2.0	−2.6
Tomatoes	−0.50	−2.0	−3.0	−5.0	−10.0	–
Lettuce	−0.15	−0.3	−0.5	−0.75	− 1.1	−1.5
Green beans	−0.40	−2.4	−3.3	−4.0	− 4.5	−4.95
Melon	−0.50	−2.2	−3.6	−6.0	− 9.5	–
Forage						
Alfalfa (hay)	−0.40	−0.9	−1.15	−1.65	−(3-4)	–
Alfalfa (seeds)	−(4-5)	−7.5	−9.1	−(10-11)	–	–
Clover (hay)	−0.5	−2.15	−3.1	−4.0	− 5.0	–
Perennial	(0.25-1)	−2.75	−3.75	−4.6	–	–
Annual	−0.40	−1.0	−1.75	−3.0	− 4.25	–
Fiber						
Cotton	−0.60	−2.5	−7.5	−9.75	–	–

Resumen

Se describe un modelo para definir la frecuencia operacional de riego para obtener máxima producción de los cultivos.

El modelo usa como información básica la respuesta de la planta a las condiciones de humedad en el suelo, características de retención y movimiento del agua en el suelo, evapotranspiración y demanda atmosférica.

Se presentan los resultados de la aplicación del modelo en cultivos de tomate y frijol, en un suelo franco arenoso. Se discute el uso de la información mundial de la relación entre rendimiento de los cultivos y el potencial matricial de agua en el suelo.

Summary

A model to define operational frequency for maximum yield of crops is described. Plant response to soil moisture conditions, soil water retention and transmission characteristics, evapotranspiration and atmospheric demand are the basic information used in the model. Results of the application of the model for tomatoes, and beans in a sandy loam soil are presented. The use of world data of the yield-water relationship is discussed.

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