IRRIGATION SCHEDULING USING ICSWAB MODEL[1]

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ABSTRACT - The paper presents a simple method of irrigation scheduling using ICSWAB model for dry land crops. The main inputs to this approach are daily precipitation or irrigation amounts and open pan evaporation (US class 'A' pan-mesh covered). The fixed cumulative evapotranspiration procedure is better than fixed days or fixed percentage soil moisture procedures of irrigation scheduling. Fixed days procedures could be reasonably applied during nonrainy season.

Index terms: water balance, fixed time, fixed soil moisture, fixed evapotranspiration.

PLANEJAMENTO DE IRRIGAÇÃO UTILIZANDO O MODELO ICSWAB

RESUMO - Este trabalho apresenta um simples método de planejamento de irrigação utilizando o modelo ICSWAB para culturas de sequeiro. Os principais parâmetros computados são precipitação diária ou quantidade de irrigação e evaporação do tanque Classe A. O procedimento da utilização de evapotranspiração acumulada é melhor que a utilização de dias fixos ou percentagens fixas da umidade do solo para métodos de planejamento de irrigação. O estabelecimento de dias fixos pode ser razoavelmente aplicado durante a estação não chuvosa.

Termos para indexação: balanço hídrico, constante de tempo, constante de umidade do solo, constante de evapotranspiração.

INTRODUCTION

One of the major factors that limit the crop production in seasonally dry tropics is the precipitation. In these regions the rainfall patterns are erratic and droughts of varying durations are frequent, in addition, most of the precipitation occurs as high intensity storms, a major part of which may go as surface runoff. Runoff could be collected and used economically as supplemental irrigation for better crop production, as the potential for runoff collection and reuse appears very high in dry tropics. In addition, there could be some other means of irrigation facilities like wells, tanks, canals etc.

Therefore to make the best use of the limited available water resources in these areas, a better irrigation scheduling procedure that can be operated at minimal cost pays rich dividends to poor farmers. Limited irrigation presumably decreases crop yields; however, yield decrease may not be directly proportional to the water deficit imposed on the crop (Howell & Hiler 1975).

It is well known that most nonforage crop yields are more sensitive to water deficits (stress) at certain growth stages than at other stages even for short periods of time. The stress factor can be characterized by several different indicators like plant based, soil based, soil and climate based, and time based. However, the desired indicator in given circumstances will depend on a number of practical considerations as well as theoretical reasoning (Hiler et al. 1974).

The literature is replete with procedures of irrigation scheduling (Hiler et al. 1974).

In this study a method of irrigation scheduling in terms of relative evaportranspiration (AE/E) using ICSWAB model of Reddy (1983) is suggested. The basic data that are needed for this work are easily measurable weather parameters at low cost, namely precipitation and open pan evaporation (US Class 'A', mesh covered).

WATER USE EFFICIENCY

Depending upon the available water for supplemental irrigation or crop resistant to drought a minimum level of relative evapotranspiration (AE/E) or soil moisture (M) or fixed days (t) can be adopted for irrigation scheduling to optimize crop yields.

In literature there are several models that relate relative yields (y/y_0) to relative evapotranspiration (AE/E) (Jensen 1968, Corsi & Shaw 1974, Hiler &

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Clark 1971, Minhas et al. 1974 etc.). Water use efficiency can be increased by maintaining equal yields and decreasing applied water (Howell & Hiler 1975). To achieve this, the models of Jensen (1968) and Minhas et al. (1974) - mathematically sound and have better predictive ability - are used and derived the lower limits of AE/E for different critical stages of a sorghum crop to optimize its yields with supplemental irrigation. Howell & Hiler (1975) found that these two models explain more than 80% of yield variation when tested with the data sets of Lewis et al. (1974) and Hiler & Howell (1973).

These two models are simulated by changing (AE/E) values to achieve 90% of (y/y_0) for the three critical growth stages of grain sorghum. The limits of AE/E obtained under this condition are given in Table 1 as an example. These limits vary according to crop(s) or cropping pattern. These results are used in presenting the irrigation scheduling using ICSWAB model. Following the same procedure the critical values of AE/E can be developed for different crops/cropping pattern.

IRRIGATION SCHEDULING USING ICSWAB MODEL

The ICSWAB model of Reddy (1983) is simple and successfully differentiates between fallow and cropped areas and adequately accounts for differences in the evaporative demand as well as soil and crop factors. The growth stage of a crop is represented by coefficients which are based on leaf area index and the percentage of light intercepted by the crop. Use of crop growth stage coefficients permits the model to account for variable available water at different stages of crop growth. Maximum available soil moisture in the top 10-cm soil layer and also in the total profile is an important input in the model. Available water in the top 10-cm soil layer at a given stage is used to determine the potential evaporation demand. The evaporative demand is represented by a function of open pan evaporation (US Class 'A' mesh covered). Actual evapotranspiration is computed as a function of time after wetting of the soil irrespective of available soil moisture. Hence, in extraction of water, the model gives preference to recent rains which wet the top layers of the soil compared to water in the deeper layers.

The main inputs to the model are easily measurable parameters such as rainfall and pan evaporation. The ICSWAB model was tested for different locations, soils, climates and crop conditions and good agreement between observed and estimated evapotranspiration and soil moisture storage has been obtained. The final form of the model is written as:

TABLE 1. Limits of AE/PE for three growth stages of grain sorghum to obtain 0.90 of (y/y_0) using Jensen (1968) and Minhas et al. (1974) models.

Model	Parameter	Critical level of AE/PE or AE/E*		
		Stage**1	Stage 2	Stage 3
Jensen (1968)	AE/PE	0.41	0.83	0.53
	AE/E	0.35	0.71	0.45
Minhas et al. (1974)	AE/PE	0.47	0.75	0.56
	AE/E	0.40	0.64	0.48
Average	AE/PE	0.44	0.79	0.55
	AE/E	0.37	0.67	0.47

* AE/PE = 0.85 AE/E

** Stage 1. Late vegetative to early boot (35 to 45% of days from emergence).

Stage 2. Boot through bloom (45 to 65% of days from emergence).

Stage 3. Milk through soft dough (65 to 85% of days from emergence).

$$\left[AE/E\right]_n = \left[1.0 + \frac{5.0 - E_n}{16.0}\sqrt{\frac{t_n}{E_n}}\left[\mathrm{Exp}\left\{(a - t_n)/b_n K\right\}\right]\right]$$

where n = day number (1, 2, ...)
(AE/E) = relative evapotranspiration (AE = actual evapotranspiration; E = open pan evaporation-mesh covered);
K = maximum available soil moisture storage capacity of the soil in the root zone, mm;
a = number of days following a rainy day for which the available soil moisture in the top 10-cm soil layer can meet potential evaporative demand;
t = time after rain or irrigation, in days (= 1, 2, 3, ... in which 1 stands for the rainy day, 2 for the first nonrainy day, 3 for the second nonrainy day etc.);
b = crop growth stage coefficient (varies with crop/cropping pattern).

Under different evaporative demand situations (E = 3, 5, 7, 9, 11, 13 and 15 mm), soil water holding capacities (K = 50, 100, 150, 200, 250 and 300 mm) and stages of crop growth (b = 0.06, 0.18, 0.24, 0.15) the time (days) taken or cumulative water loss through evapotranspiration (ΣAE) or level of percentage soil moisture (MX100/K) reached to achieve the defined lower limits of AE/E were computed using the above equation. The time in full days is presented in Table 2; the percent soil moisture is given in Fig. 1 and the cumulative evapotranspiration (ΣAE) is presented in Fig. 2a, b and c for the three limits of AE/E, namely 0.4, 0.5 and 0.6. In all these cases it was assumed that at the start the soil is at field capacity.

Scheduling in terms of fixed days

Table 2 presents the number of days taken to reach the specified lower limit of AE/E under different soil types (K), evaporative demands (E) and stages of crop growth (b). For example, under E = 3 mm/day and b = 0.06, AE/E will reach 0.4 in 4 days in sandy soils with K = 50 mm and in 32 days in deep black soils with K = 300 mm. Similarly under E = 3 mm/day, AE/E reaches 0.4 with in 4 days at the beginning of crop growth with b = 0.06 and it takes 15 days after vegetative phase when b = 0.24 in sandy soils (K = 50 mm); and 32 days under b = 0.06 and 116 days under b = 0.24 in deep black soils (K = 300 mm). Therefore, fixed time irrigation scheduling under different climatic, soil and crop growth stage conditions is quite appropriate for the better utilization of scarce water supply.

The above patterns are clearly evident from the lysimetric study for chickpea Reddy (Prelo).

This method of irrigation scheduling is easy and most economical. Within a reasonable accuracy one can adopt this procedure even with average open pan evaporation data having irrigation facility in the nonrainy season. In the rainy season with frequent rains this approach fails.

Sheduling in terms of percentage soil moisture

Fig. 1 presents the percentage available soil moisture levels at which one has to irrigate to achieve the necessary lower limits of AE/E viz., 0.3, 0.4, 0.5 and 0.6 at different stages of crop growth. This method also fails in rainy season as the water that is available in the top layers of soil during rainy spells will give different weightages to AE/E rate compared to the soil moisture that is available in the deeper layers of the soil. That is, it is more important "where is the soils moisture" rather than "how much is the soil moisture".

Scheduling in terms of cumulative evapotranspiration

Fig. 2a, b and c present at what value of cumulative evapotranspiration (ΣAE) one has to irrigate at different stages of crop growth under different soil water holding capacities to achieve the necessary lower limit of AE/E. This procedure could be adopted under both rainy (or irrigated) and nonrainy conditions. This can be easily monitored using the above equation by adopting a simple book-keeping procedure. This can be done even without the aid of sophisticated computers or calculators. The operation of this approach is very simple. For example, if the cumulative evapotranspiration ΣAE is 40 mm between any two rainy spells or irrigations and

TABLE 2. Irrigation scheduling for dry land crops in terms of days.

E (mm/day)	The lower limit of (AE/E)	Irrigation, days																							
		K = 50 mm				K = 100 mm				K = 150 mm				K = 200 mm				K = 250 mm				K = 300 mm			
		Growth stage of the crop (b)																							
		0.06	0.18	0.24	0.15	0.06	0.18	0.24	0.15	0.06	0.18	0.24	0.15	0.06	0.18	0.24	0.15	0.06	0.18	0.24	0.15	0.06	0.18	0.24	0.15
3	0.6	2	7	9	6	7	17	22	14	11	27	36	23	15	37	50	31	19	49	67	41	24	62	83	52
	0.5	3	9	12	7	8	20	27	17	13	33	44	28	17	45	61	37	22	59	80	49	28	74	99	61
	0.4	4	11	15	9	9	25	33	21	15	40	53	33	20	54	73	45	26	71	95	59	32	88	116	73
5	0.6	2	5	7	4	5	11	14	9	7	16	21	14	10	22	28	19	12	28	36	24	15	34	43	29
	0.5	3	7	9	6	6	14	18	12	9	21	28	18	12	29	37	25	15	36	47	31	18	43	56	37
	0.4	3	9	12	7	7	18	24	15	11	28	36	23	15	37	48	31	18	46	60	39	22	56	22	47
7	0.6	1	3	4	3	3	7	9	6	5	11	13	10	6	13	16	12	8	16	19	14	10	19	22	17
	0.5	1	5	6	4	4	10	13	9	7	15	19	13	8	18	23	16	10	23	27	20	13	26	32	23
	0.4	2	7	9	5	5	14	17	12	8	20	25	17	11	25	31	22	14	31	38	27	16	36	43	31
9	0.6	1	3	4	2	3	6	7	5	3	7	9	7	5	9	11	8	6	10	12	9	7	12	13	4
	0.5	1	4	5	3	4	8	10	7	5	11	13	9	7	13	16	12	8	15	18	14	10	17	20	16
	0.4	2	6	7	5	5	11	14	10	7	15	18	13	9	19	22	17	11	21	25	19	13	24	28	22
11	0.6	1	2	3	2	2	4	5	3	3	6	6	5	4	6	7	6	5	7	8	7	5	8	9	8
	0.5	1	3	4	3	2	6	7	5	4	8	10	7	5	10	11	9	7	11	12	10	7	12	13	11
	0.4	2	5	6	4	4	9	11	8	6	12	14	11	7	14	16	13	9	16	18	15	10	17	19	16
13	0.6	1	2	2	2	1	3	4	3	3	4	5	4	3	5	5	5	3	5	6	5	4	6	6	6
	0.5	1	3	4	3	2	5	6	4	4	7	8	6	4	8	8	7	5	8	9	8	6	9	10	9
	0.4	2	5	6	4	3	7	9	7	5	10	11	9	6	11	12	10	7	12	13	11	9	13	14	12
15	0.6	1	2	2	1	1	3	3	2	2	4	4	3	3	4	4	4	3	4	5	4	4	5	5	5
	0.5	1	3	3	2	2	4	5	4	3	6	6	5	4	6	7	6	4	7	7	6	5	7	8	7
	0.4	2	4	5	4	3	6	7	6	5	8	9	8	6	9	10	9	6	10	10	9	7	10	11	10

the critical limit for irrigation is 80 mm and rainfall of 30 mm occured on the day then on that day ΣAE = 40-30 = 10 mm. Therefore, one can still wait until a loss of 70 mm from the soil.

Booking keeping procedure:

- using the daily rainfall or irrigation and open

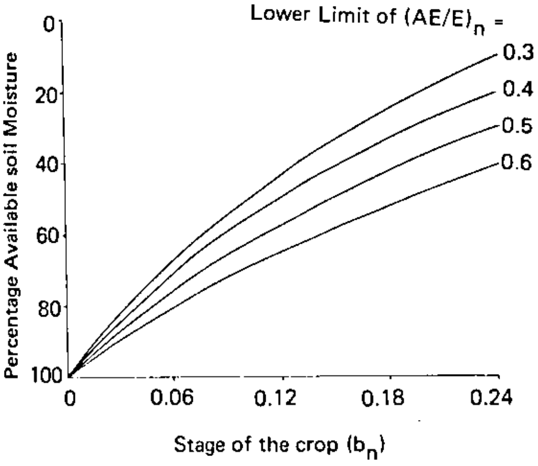

FIG. 1. Irrigation scheduling interms of available soil moisture in the root zone using ICSWAB model.

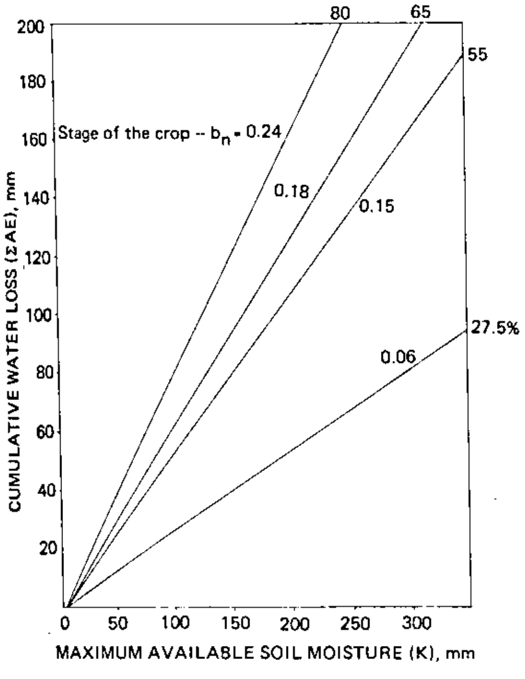

FIG. 2a. Irrigation scheduling based on ICSWAB model with a minimum limit of $AE_n = 0.4\ E_n$.

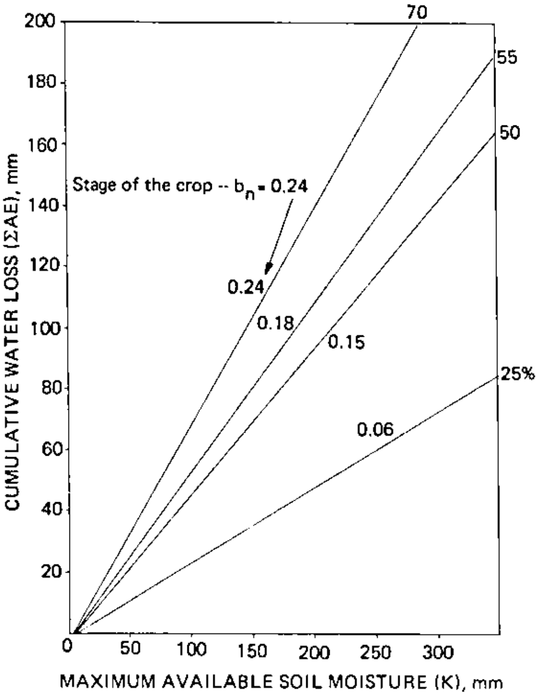

FIG. 2b. Irrigation scheduling based on ICSWAB model with a minimum limit of $AE_n = 0.5\ E_n$.

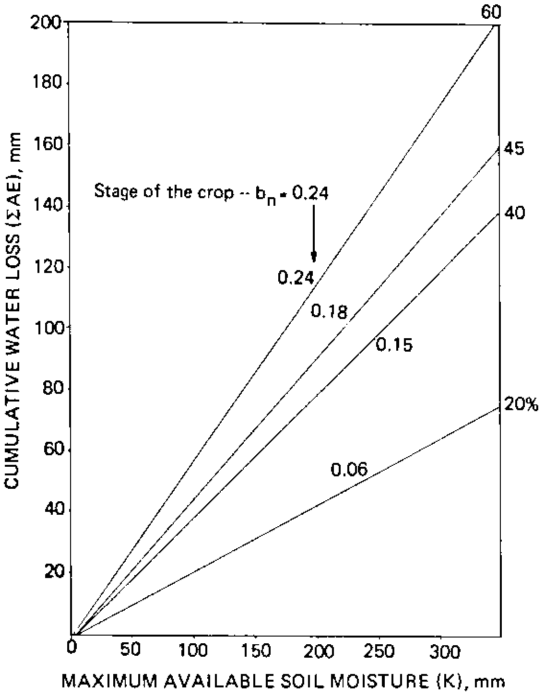

FIG. 2c. Irrigation scheduling based on ICSWAB model with a minimum limit of $AE_n = 0.6\ E_n$.

pan evaporation data compute $(AE/E)_n$ using the above presented equation (Reddy 1983) for each day;

- compute AE_n as $(AE/E)_n \times E_n$;
- compute ΣAE_n between any two rainy spells or irrigations;
- reset on a rainy day as $\Sigma AE_n = \Sigma AE_n - R_n$;
- check whether ΣAE_n is less than or equal to the limit specified for that stage and if this value is nearly equal to the specified limit than give irrigation;
- reset the $\Sigma AE_n = 0$ on the irrigation day.

CONCLUSIONS

This study presents an easy and simple procedure for irrigation scheduling. This procedure could be operated by following a simple book-keeping procedure. This procedure does not require a sophisticated computer or calculator. Where the computer facilities are available using this procedure few regions could be easily monitored that even facilitate advance forecasting of yields. This procedure is built up using the ICSWAB model of Reddy (1983). The minimum crop water requirements could be computed using Jensen (1968) and Minhas et al. (1974) yield models. Three probable procedures of irrigation scheduling, namely, fixed time, fixed percent soil moisture and fixed cumulative evapotranspiration are discussed. Under rainfall situation the fixed cumulative evapotranspiration is more appropriate. During the nonrainy season the fixed time procedure also could be used in addition to fixed cumulative evapotranspiration procedure.

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