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Application of "PLANTGRO", a water use model for differentially irrigated pearl millet

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ABSTRACT

The performance of PLANTGRO (Hanks, 1985) in simulating evapotranspiration (ET) and grain yield of differentially irrigated pearl millet was tested. PLANTGRO has over-estimated ET under stressed and under-estimated under non-stressed conditions. It also over-estimated the yield under stressed conditions. An analysis of the individual functional relations of PLANTGRO revealed a need to evolve site specific partitioning factor separating potential ET into evaporation and transpiration; lower limit of soil water availability and root growth functions for pearl millet.

Key words : Pearl millet, Irrigated, Water use model, PLANTGRO

The need for efficient water use is becoming increasingly important as water for crop production becomes limited and costs of water increase. The goal of irrigation scheduling is to determine accurately crop water requirements and to match water application to these requirements in a timely and efficient manner. Models have been developed using various approaches and levels of details to predict crop water requirements. Hanks (1985) proposed a one-dimensional model based on hydrological cycle to predict dry matter and / or grain production of crops which has been used extensively at several locations for crops like wheat (Hanks and Puckridge, 1980), sugar beet (Davidhoff and Hanks, 1989) and Indian mustard (Patel, 1994) with good success. However, the performance of this model for pearl millet, a crop considered to be drought tolerant, is yet to be evaluated. Here, an attempt has been made to validate PLANTGRO for irrigated pearl millet.

MATERIALS AND METHODS

The data utilized were collected from a field study conducted for two summer seasons of 1995 and 1996 at the Department of Agricultural Meteorology, Gujarat Agricultural University, Anand Campus, Anand. The soil of the test site was a sandy loam, vernacularly called as *Goradu* soil, Which is alluvial in origin belonging to Entisols (Typic Ustorthents). The 0-90 cm soil layer had on average a bulk density of 1.45 g cc^{-1}, saturated hydraulic conductivity of 1.93 cm hr^{-1}, saturated moisture content of 0.369 cm cm^{-3}, field capacity of 0.189 cm cm^{-3} and permanent wilting point moisture of 0.079 cm cm^{-3}.

Pearl millet Cv. GHB-30 was sown on 3 dates (5^{th}, 15^{th} and 25^{th} February) superimposed with four irrigation regimes (irrigation at IW/CPE ratio of 1.0, at 25%, 40% and 60% depletion of available soil moisture

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i.e., ASMD). The treatments were laid out in a split plot design and were replicated four times. The crop was sown adopting 45 X 15cm spacing and received a fertilizer dose of 80:30:0 kg NPK ha^{-1}. The entire quantity of P and 50 per cent N were applied basally and remaining half applied in two equal splits at first irrigation and at flowering. The crop was given two common irrigations, at sowing and at 20 days after sowing (DAS). Subsequent irrigations were given as per the treatment schedule with a fixed amount of 50 mm depth of water using parshall flumes.

The evapotranspiration (ET) was estimated using the soil water balance equation. The ground water table was more than 10 m deep and hence the contribution of ground water towards the crop ET is considered negligible. Soil moisture determination was made from the first common irrigation onwards with two pre-calibrated neutron probes (Troxler Inc., USA) at 22.5, 37.5, 52.5, 75.0 and 105.0 cm depths with an assumption that the counts were for the average depths of 15-30, 30-45, 45-60, 60-90 and 90-120 cm, respectively. Soil samples were collected for the same depths at 10-day interval. Soil moisture content in the surface 0-5 and 5-15 cm was determined at 3-day interval by collecting samples with tube auger. The depth of the root system was determined by collecting soil samples with the help of core sampler from an area of 22.5 X 7.5 cm and 15 cm depth-wise at 10-day interval. Each soil thus collected was separated carefully into three equal parts representing 5cm soil thickness.

The PLANTGRO model of Hanks (1985) was written in BASIC language. A simplified flow chart of PLANTGRO is presented as Fig. 1. The model needs daily potential evapotranspiration (PET) values as input and hence, the user has the option to choose the appropriate method to estimate the values of PET as per the availability of meteorological parameters. In the present investigation, the values of the PET estimated by the modified Penman method (Doorenbos and Pruitt, 1979) were used as input.

RESULTS AND DISCUSSION

Estimated Vs observed ET

The pearl millet evapotranspiration (mm day^{-1}) as simulated by PLANTGRO against observed ET for a stress free I_2 (I_2-irrigation at 25% ASMD) and a stressed I_4 (I_4-irrigation at 60% ASMD) treatment for all the three dates of sowing is compared and the results are presented as Fig.2, 3 and 4. The results on comparison for D_1 (Fig.2) showed that in I_2 level of irrigation, the PLANTGRO model had over-estimated between the period from 21-31 DAS and under-estimated the same during the period from 33-91 DAS. The ET estimated by the PLANTGRO model for I_4 treatment during the period from 21-28 DAS was closest to the observed ET but it was higher after the period from 58 DAS. In the second date of sowing (D_2 I_2 and D_2 I_4), the PLANTGRO estimated ET followed the trend similar to that observed in first date as evident from the Fig.3. The estimated ET during 21-30 DAS was closer to the observed in I_2 treatment and in I_4 treatment, ET was over-estimated by PLANTGRO after 52 DAS. In the third date of sowing (D_3), which had the shortest crop duration, the PLANTGRO had over-estimated ET after 50 DAS (Fig.4). The deviation in the predicted ET was large under the stressed condition. The observed and model predicted ET were subjected to statis

Table 1: Statistical analysis of the observed and model predicted ET

Treatment	RMSE	MBE	MPE
D_1I_2	2.012	-0.052	3.16
D_1I_4	3.451	2.822	81.67
D_2I_2	1.935	-0.403	6.73
D_2I_4	2.737	2.616	78.16
D_3I_2	3.004	0.067	29.53
D_3I_4	4.163	2.313	95.36
Mean	2.884	1.227	49.10

tical analysis using mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE). The results of the analysis are presented in Table 2. The results based on the MBE values showed that PLANTGRO has over-estimated ET for stressed treatments and under-estimated for non-stressed condition. The MPE values indicated that PLANTGRO performed better for non-stressed level of irrigation than for stressed levels of irrigation, and large MPE values were noticed for both these conditions when the length of crop duration was shortened by delayed sowing. On an average for all the treatments, the PLANTGRO has predicted ET only with 51 per cent agreement.

Functional relations of PLANTGRO

Partitioning of PET

The PLANTGRO requires that the PET is to be separated into potential soil evaporation (Esp) and potential transpiration (Epp). This was carried out in the present investigation, as suggested by Hanks (1985), based on the following assumptions. The relative potential transpiration (Epp/PET) was assumed to be zero or close to zero from planting until the start of rapid growth (from 0 - 25 DAS). At full cover, this was assumed to be a fraction less than one. Linear relationship was used to compute this between the two stages. Relative potential evaporation (Esp/PET) was then computed as (1-Epp/PET) for all phenophases except for the maturity phase. During maturity, Epp/PET decreased due to leaf senescence and decreased linearly to zero from the start of maturity to harvest. The comparison presented in Fig.2 for non-stressed treatment revealed that PLANTGRO predicted ET matched closely with observed ET during mid part of the crop season. During the early part and again towards maturity the root water uptake function envisaged in the model did not match with that observed. For a stressed treatment, the model predicted ET was close to the observed only during the early part of the season and up to 55 DAS and thereafter the model gave over-estimates. Soil evaporation (Es) in PLANTGRO is estimated at a single stage using the expression

$$Es = PET/t^{0.5}$$

where, t is time in days from the soil was last wetted. The evaporation process is constrained in two ways. The water loss by evaporation from the soil occurs only from the top layer and the top layer is allowed to lose water to a point below wilting point to the air-dry moisture content. The top layer of soil in the model is assumed as 20 cm thick and the air-dry moisture content as 2 per cent by weight. The water loss from wilting to air-dry moisture content occurs only from the top 10cm layer of the soil. However, in the present study, the evaporation function was modified as

$$Es = PET / t^{0.3}$$

This is because, the soil is sandy loam and loses soil moisture more readily than at the rate assumed in PLANTGRO. In the present study, however, no attempt has been made to alter the thickness of top layer and the thickness of the layer from which water loss occurs beyond wilting point. This needs to be investigated either from field studies or by iterative technique of the PLANTGRO.

In PLANTGRO model, transpiration is assumed to proceed at a potential rate until some level is reached, below which it proceeds at a rate lower than the potential rate. Transpiration is related to soil water status as

$$T = PET \quad \text{if } SWS/AW > b$$
$$T = Tp\,[\,SWS/(AW * b)] \quad \text{if } SWS/AW < b$$

where,

SWS = actual available soil water storage in a given layer at any time

AW = maximum available soil water storage

b = fraction of SWS/AW below which transpiration will be limited.

In the present study, the value of b was taken as 0.5 as suggested by Hanks (1985). However, the results of the comparison in Fig.2 suggest that the value of b need to be determined for drought tolerant crop like pearl millet.

Root growth function

Simulated transpiration is largely dependent on the two parameters viz., the availability of soil water and interception of water through the root growth. The root growth function of PLANTGRO was compared with the observed root growth as a mean for all treatments and the results are presented as Fig.5. The results indicated that the model has over - estimated and a peak value of 45.0 cm was attained by 42 DAS itself and remained

Table 2: Comparison of observed and simulated grain yields (q ha^{-1}) of pearl millet

Treatment	Observed yield	Estimated yield	Per cent deviation
D_1I_1	22.52	24.68	+ 9.59
D_1I_2	28.05	27.84	- 0.75
D_1I_3	21.65	28.02	+ 29.42
D_1I_4	20.85	26.28	+ 26.04
D_2I_1	29.35	28.78	- 1.94
D_2I_2	31.22	31.20	- 0.06
D_2I_3	29.29	31.22	+ 6.59
D_2I_4	28.46	30.75	+ 8.05
D_3I_1	25.61	28.82	+ 12.53
D_3I_2	28.82	28.82	0.0
D_3I_3	28.00	28.82	+ 2.93
D_3I_4	23.83	28.82	+ 20.94

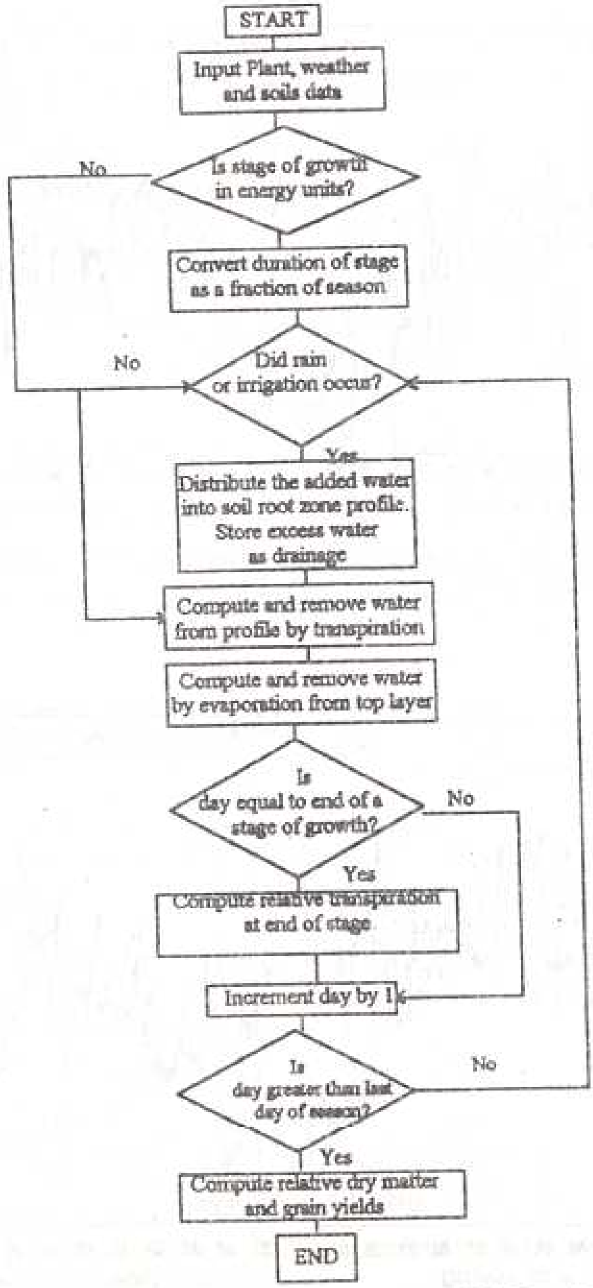

Fig. 1: Simplified flow chart of PLANTGRO model

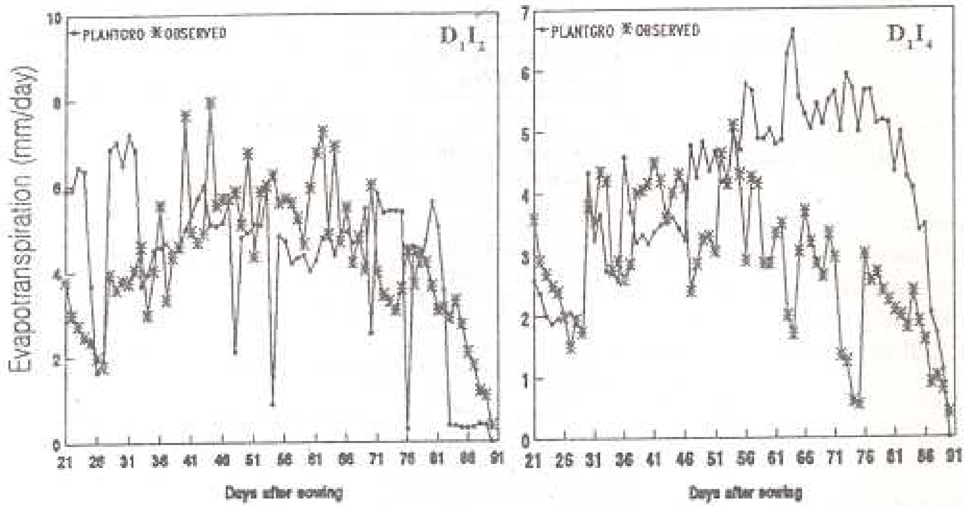

Fig.2: Comparison of observed and model predicted ET for D_1

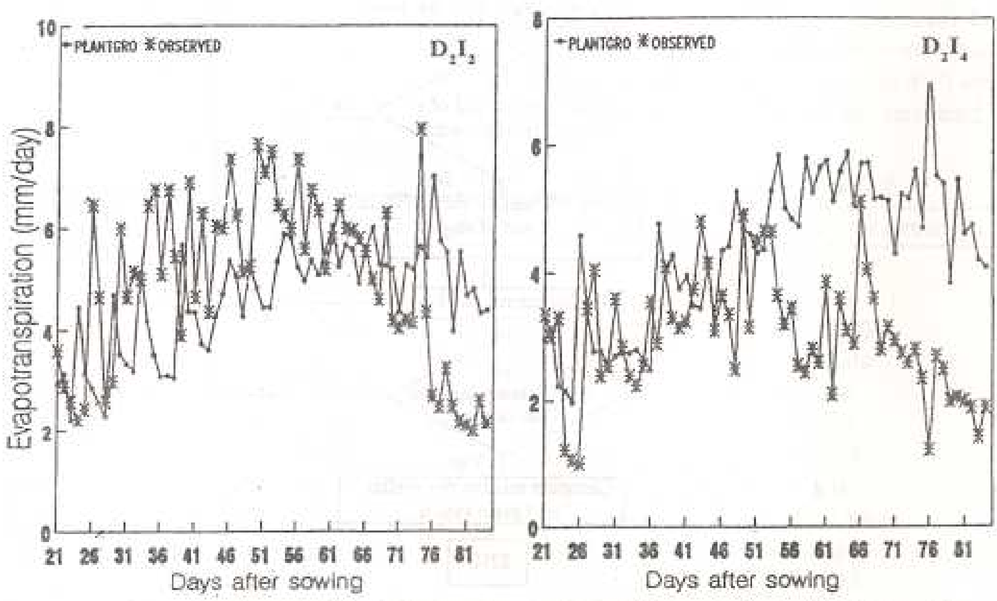

Fig.3:Comparison of observed and model predicted ET for D_2

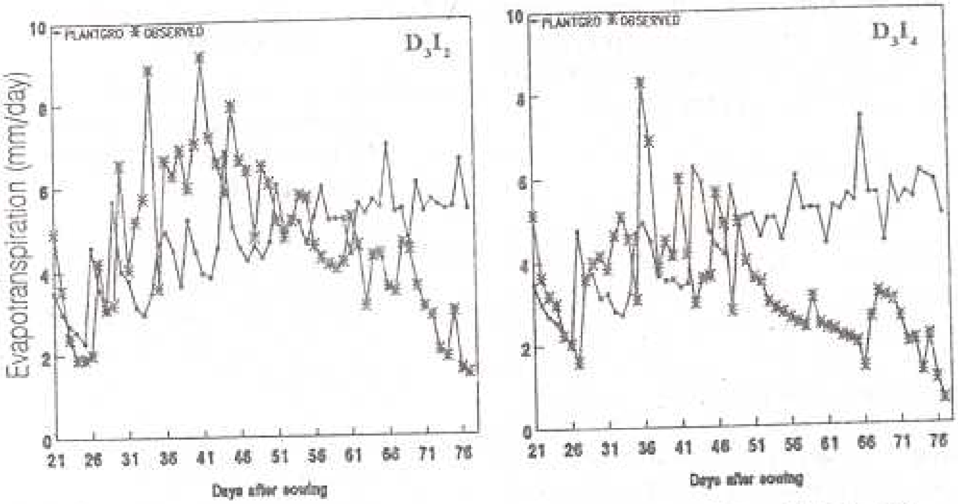

Fig.4: Comparison of observed and model predicted ET for D_3

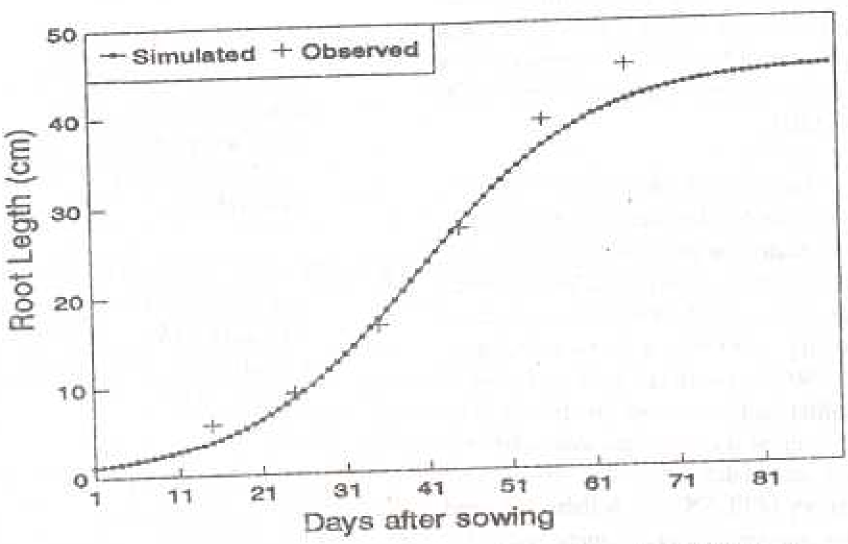

Fig.5: Comparison of simulated and observed root growth

constant thereafter. The over-estimation and a high value very early in the season might have allowed more quantity of water available for ET which might be the reason for the over-estimation of ET in the present study.

Observed Vs estimated yield

PLANTGRO estimates the crop yield by relating the relative yield to relative transpiration. The results of observed and estimated grain yields are presented in Table 3. PLANTGRO over-estimated yield under stressed conditions. The estimated yields were close to the observed for the second date of sowing. The large deviation from observed values in the first date of sowing might be due to the long crop duration (92.5 days) compared to the third date of sowing (82 days) which has resulted in higher estimated seasonal transpiration values. Again, PLANTGRO over-estimated yield under severely stressed treatment (irrigating at 60% ASMD) compared to a moderately stressed treatment (irrigating at 40% ASMD).

The PLANTGRO model has over-estimated the ET for stressed and mostly under-estimated for non-stressed conditions. The mean percentage error values indicated that the model could be used for irrigation scheduling under water adequacy. PLANTGRO over-estimated the seed yield of pearl millet under stressed conditions. The deviations in yield estimations were relatively small for second date of sowing. To improve the accuracy of PLANTGRO, there is a need to evolve site-specific partitioning factor for separating PET into evaporation and transpiration; lower limit of soil water availability and root growth function.

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