SEASONAL CHANGE OF DI-VALUES (DRYNESS INDEX) AND MODELING OF SOIL MOISTURE MOVEMENT IN THE CERRADO REGION

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SUMMARY - To estimate the water loss from cultivated fields in the Cerrado region, the actual (AET) and the wet environmental evapotranspiration (PET) were calculated, and the soil water movement of irrigated fields were simulated using the "TANK" model. The AET and PET values were estimated by using the Morton method (1983) based on general meteorological data. The seasonal changes of the soil dryness index (DI) were calculated using these evapotranspiration values. The DI which was very low in the rainy season(October - April), increased after the end of the rainy season, gradually from the value of 0.7 to 0.8 in the mid-dry season. There was a good agreement between the soil moisture data measured in the upland field, by using tensiometers and the ones calculated based from TANK model. This agreement suggests that the TANK model can be used to estimate the soil water movement from an upland field based on the precipitation and the physical properties of soil recorded in this area.

1. Introduction

The Cerrados of Brazil account for about 21 percent of the total land area (850 x 10^4 km^2) of the country. The annual mean temperature in this region ranges from 22°C in the southern part to 27°C in the northern part. The monthly mean temperature at CPAC which is located in the center of the region varies from 26.7 °C in October to 17.7°C in July. Although annual precipitation generally amounts to 1200-1800 mm, 90 percent is concen trated in the warm rainy season from October to April: the remaining period of the year is the dry season with scanty precipitation. Morever, the warm rainy season is often interrupted by considerably long dry spells called "Veranico". These water balance conditions limit the crop season and contribute to the instability of production in the Cerrados.

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The major strategy for efficient and stable crop production in the region is, therefore, to develop adquate irrigation techniques and suitable cropping systems involving irrigation for the respective sub-regions.

In the present paper, the Morton model was used to estimate the actual (AET) and potential evapotranspiration (PET). The results obtained were analyzed to examine the seasonal changes in daily precipitation, dryness index (DI) and irrigation requirement.

On the other hand, various researchers have attempted to develop a method of estimation of the soil water movement based on meteorological data. In the present study, the "TANK-model" method was applied to make an accurate forecast of the discharge in the drainage basin. The TANK-model method was evaluated in order to estimate the soil water content and the ground water level in the upland fields of the Cerrados.

This study was carried out as a part of the research programme under the Japan-Brazil Agricultural Research Cooperation Project.

2. Materials and Methods

2.1 Estimation of actual and wet environmental evapotranspiration

The method based on the Morton's model (Morton, 1983) is described in Appendix 1. ETW and ETP, and consequently AET, were calculated without tuning empirical coefficients in the model. The calculations were made for the weather station of CPAC in this region using mean values of air temperature covering a five and ten year period, and relative humidity, sunshine dura-tion, precipitation recorded during the period from 1978 to 1990.

Appendix 1

The Morton model (1983) was used to estimate the actual evapotranspiration (AET).

$$A_{ET} = 2E_{TW} - E_{TP}$$

$$E_{TP} = R_T - \lambda\, f_T\, (T_P\text{-}T)$$

$$R_{TP} = E_{TP} + \Upsilon\, pf_T\, (T_P\text{-}T)$$

$$E_{TW} = b1 + b2\,(1 + \Upsilon\, p/\Delta_P)^{-1}.R_{TP}$$

where E_{TW} (PET) is the wet-environmental actual evapotranpiration ($W.m^{-2}$), E_P is the potential evapotranspiration ($W.m^{-2}$), R_T is the net radiation for the soil plant surface at ambient temperature, R_{TP} is the net radiation ($W.m^{-2}$) for the soil plant surface at the potential evapotranspiration equilibrium temperature (T_P, °C), T is the average of maximum and minimum temperature (°C), f_T is the water vapor transfer coefficient ($W.m^{-2}.mb^{-1}$), λ is the heat transfer coefficient (mb. $°C^{-1}$), p is the atmospheric pressure (mb), Δ_P is the slope of the saturation vapor pressure temperature curve at T_P, Υ is a psychrometric constant, b_1 and b_2 are empirical constants with values of $14W.m^{-2}$ and $1.20W.m^{-2}$, respectively.

In the model, net radiation is estimated from the following empirical equation:

$$RT = (1-a_L)\,St + 0.92\,\sigma\,(T + 273)^4 * [1 - (0.71 + 0.007 e_a p/ps)(1 + \rho)$$

$$St = D.So + (0.08 + 0.30D)(1 - D)\,Se$$

where St is the incident solar radiation ($W.m^{-2}$), So is the clear sky global solar radiation ($W.m^{-2}$), Se is the extra-atmospheric global solar radiation ($W.m^{-2}$), D is the ratio observed to maximum possible sunshine duration, a_L is the minimum albedo, e_a is the vapor pressure of air (mb), ρ is a function of the cloud cover or D, σ is the Stefan-Bolzman constant, p/ps is the ratio of atmospheric pressure at the station to that at sea level.

2.2 Physical properties of the oxisoil profile in the Cerrados

The amount of water that can be stored in soil for plant growth is very important for agriculture, especially in areas with a distinct dry season. The physical properties of the Cerrado soils were investigated by several researchers. Figure 1 shows the physical properties of the soil profiles analyzed at CPAC by Hayasaka & Freitas Jr. (1987). Pits 1 and 2 represented the upland field with red-yellow soil and the orchard field with dark-red latosol. As in the case of the field capacity, the solid phase accounted for about 35-45 percent of all the soil profiles. The water content-pF curves of representative soils using undisturbed samples are presented in Figure 2. Data on the Cerrado soils were reported by Kubota & Carvalho (1983), Hayasaka & Freitas Jr. (1987), Iwama et al. (1987) and Miyazawa et al. (1990). The measurements were performed from the ground surface to a 1.0 m depth for each horizon with 2-3 replications in the cultivated field of CPAC and Cerrado region.

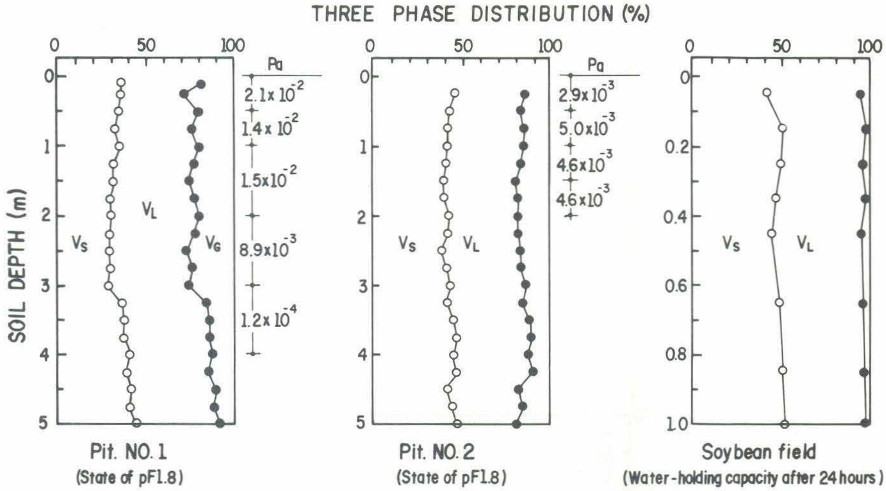

FIG. 1 - Physical properties of soil profile at CPAC in Cerrados.

The non-linear regression analysis of the plotted data in Figure 2 indicates that, the relationship between the volumetric soil water content (%) and the pF-value can be well approximated by the equation:

$$Y = 64.76-5.31 * X-5.38 * X2+1.07 * X3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

where Y is the volumetric soil water content (%) and X is the pF-value. Eq. (1) can be used to estimate indirectly and easily the soil water content (vol. %) from the pF-value or soil water tension.

The calculation based on the TANK model used simulated data of the soil water content from several field crops measured by Hayasaka & Freitas Jr. (1987) and Miyazawa et al. (1990).

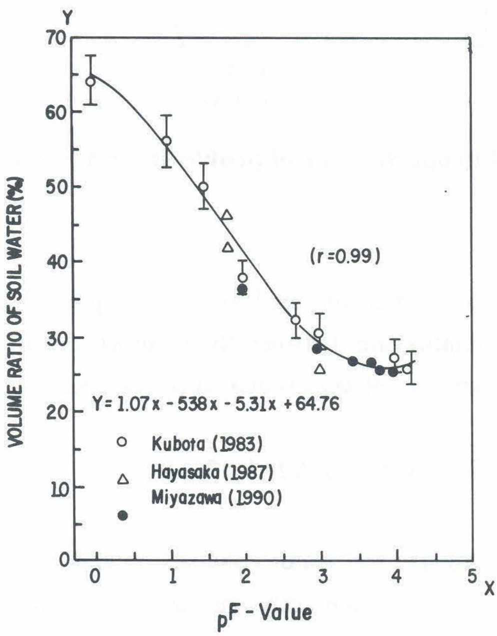

FIG. 2 - Curve representing the moisture characteristics of Cerrado soils.

3. Results and Discussion

3.1 Frequency distribution of daily precipitation

Figure 3 shows an example of the frequency distribution of daily precipitation was measured at CPAC from 1986 to 1990. It is important to indicate that in the wet season, the ratio of cloudy sky ranged from 0.307 in April to 0.697 in December, with an average value of 0.496 in the remaining period of the year, the ratio ranged from 0.033 in June to 0.180 in September.

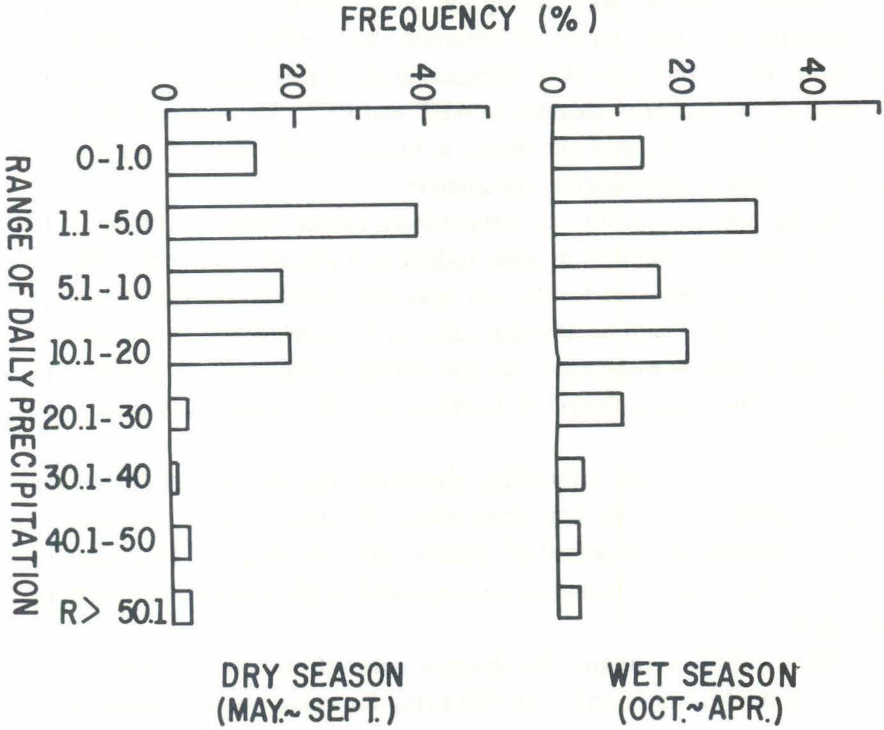

FIG. 3 - Frequency distribution of daily precipitation during the period from 1986 to 1990 at CPAC.

Figure 3 shows that the ratio of ineffective rainfall was 44.5% in the wet season and 52.8% in the dry season, while the ratio of effective rainfall fell into the range of 10.1 mm to 20.0 mm for 20 percent of cloudy days. The effective rainfall related to irrigation was defined as follows: 5.0 mm/day < $R_{*}0.8$ < 80.0 mm/day, while the ineffective rainfall was R < 5.0 mm/day and R > 80.0 mm/day in the irrigation plan of Japan. Based on this definition, the data of daily precipitation at CPAC were calculated. The effective rainfall ranged between 850 mm and 1300 mm during the wet season.

3.2 Seasonal change in AET and PET

Weather data obtained during the rainy season of 1980/81 with scanty precipitation or a long period of "veranico" and 1989/90 with abundant precipitation and a short period of veranico at the CPAC-station were analyzed in terms of the seasonal changes in AET and PET. The seasonal changes in AET and PET so obtained are shown in Figure 4 and Figure 5, together with those of related meteorological parameters.

In the wet season, the air temperature ranged from 19.0°C to 25.0°C, while the seasonal changes in solar radiation fluctuated markedly. The daily values of AET calculated for the wet season of 1989/90 were in the range of 0.8 mm to 6.0 mm with an average value of 3.5 mm, which agreed well with the average evapotranspiration for the soybean crop field measured with a lysimeter in this region (Horie & Luchiari Jr. 1981, Espinoza Garrido, Waldo 1980).

However, the relative humidity characterizing the dryness of the air decreased significantly with time from about 85 percent in the wet season to about 70 percent in the period of veranico and dry season. This significant decrease in the relative humidity corresponded to the dry spells prevailing in this region.

Ohba (1987) estimated the dryness index of the climate (DI) in Thailand using the Morton model. The following DI-value was introduced to characterize the intensity of the dry spell.

$$DI = 1 - (AET/PET) \quad \text{.................... (2)}$$

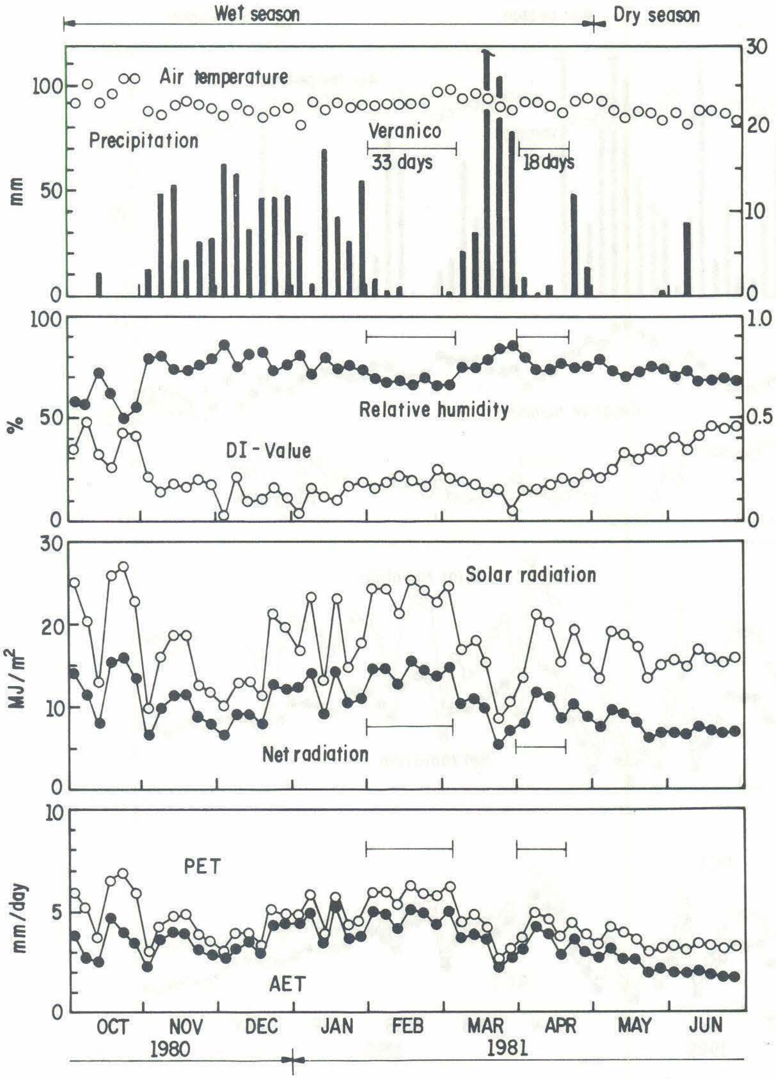

FIG. 4 - Seasonal variation of actual and potential ET, dryness index (DI) and relevant weather parameters during the period from October 1980 to June 1981.

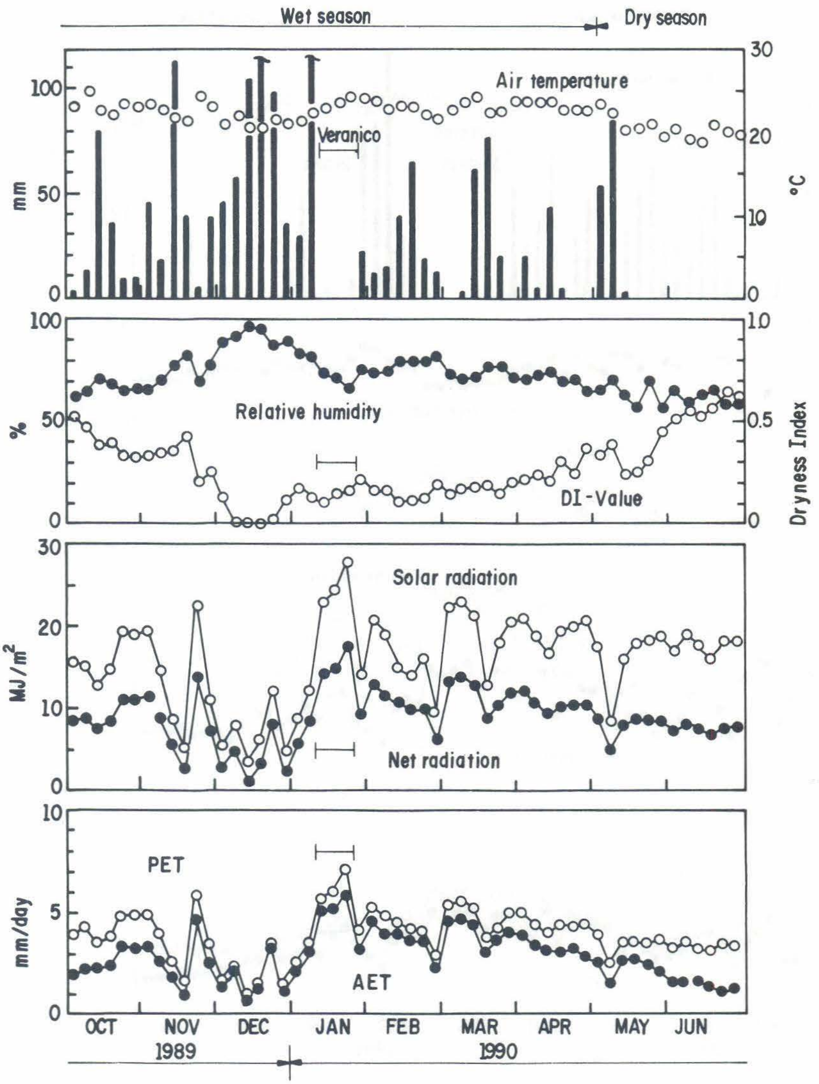

FIG. 5 - Seasonal variation of actual and potential ET, dryness index (DI) and relevant weather parameters during the period from October 1989 to June 1990.

This index is very similar to the Crop Water Stress Index (CWSI) used by several researchers (Jackson, 1982) to characterize the water stress and crop yield relationships.

At the end of the wet season, the daily DI-value increased linearly with time from 0.2 in April to 0.6 in June, and the DI-value remained at the high level of 0.7 to 0.8 during the dry season. The seasonal changes of the DI-value as described above reflected the seasonal changes of the weather parameters, particulary precipitation.

3.3 Annual changes of DI-values and irrigation requirement for selected years

Figure 6 compares the annual variations of the DI values calculated for 1983 when the precipitation was abundant and 1986 when the precipitation was scanty. No significant difference in the DI-values among these two years was observed during the dry season unlike in the wet season. In 1983 (a year with abundant precipitation), the DI-values during the wet season ranged from 0.05 and 0.25, suggest-ing that water stress was unlikely to occur. In 1986 (a year with scanty precipitation), the DI-value for the wet season ranged between 0.35 and 0.55 as observed usually during an ordinary dry season.

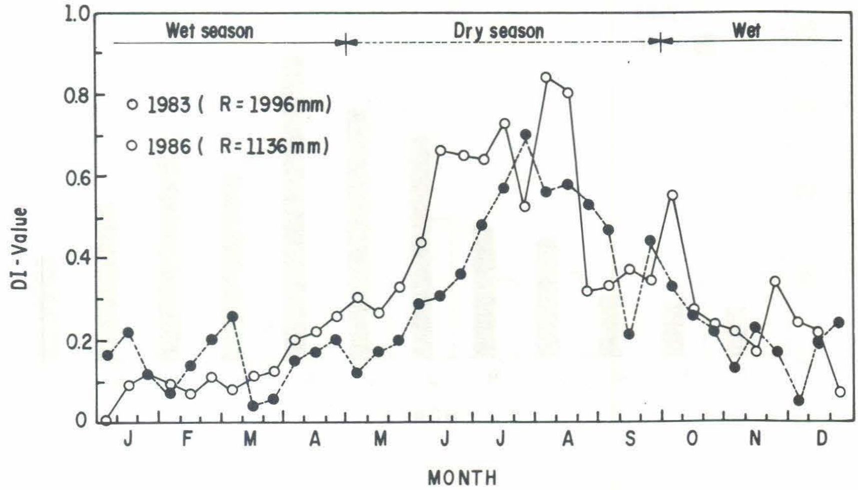

FIG. 6 - Annual changes of DI for selected two years.

Using the dryness index described above, the irrigation requirement (IR) was expressed as follows:

IR = PET.DI .... (3)

The IR-values over a 10 year period were estimated from eq.(3) using the weather data colected at CPAC for a period of 10 years. The total values of the irrigation requirement (monthly IR) over a 10 year period estimated from eq.(3), ranged from 15 mm to 40 mm in the wet season and 20 mm to 72 mm in the dry season. Based on the results shown in Figure 7, it was concluded that the irrigation requirement varied significantly depending on the seasonal changes in the dryness index characterizing the aridity of the climate.

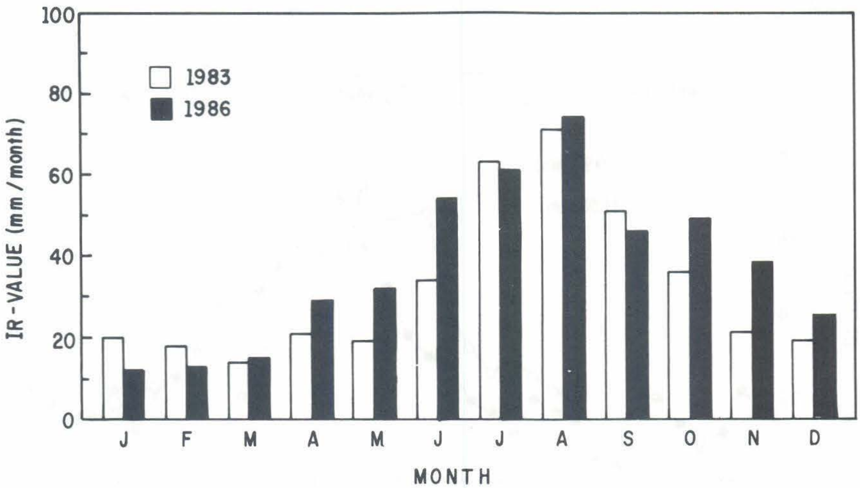

FIG. 7 - Annual changes of IR-values for selected two years.

3.4 Simulated soil moisture movement of upland field.

The movement of soil moisture is very important for crop production. The TANK model used for the estimation of the soil moisture shown Figure 8 belonged to the five-step type. The TANK coefficients described in Figure 8 were determined based on the soil water constant shown in Figure 9. The level of evaporation pore and percolation pore corresponded to a pF value of 2.7 (rupture of capillary bond) and pF value of 1.8 (field capacity), respectively. The levels of evaporation pore, percolation pore and surface runoff pore were determined empirically. Figure 10 shows the flow chart of the calculation of the soil moisture movement in a cultivated field by using the coefficient described above. The results obtained enabled to compare the estimated soil moisture with the measured one in the upland field shown in Figures 11 and 12.

These figures show that there was a good agreement between the soil moisture data measured in the upland field using a tensiometer and the soil moisture calculated from the TANK model. The results showed that the soil moisture calculated from the TANK model enabled to determine the soil moisture movement at a soil depth with a higher soil moisture with an accuracy in the order of ±10%. As an example of the long period of veranico in recent years (1981), we estimated the soil moisture content of the upland field. The results obtained are shown in Figure 13. The plow sole (0-50 cm) decreased from 200 mm to 156 mm at the end of veranico.

These findings suggest that the TANK model can be applied to estimate the soil moisture movement from an upland field based on the precipitation and physical properties of soil recorded in this region.

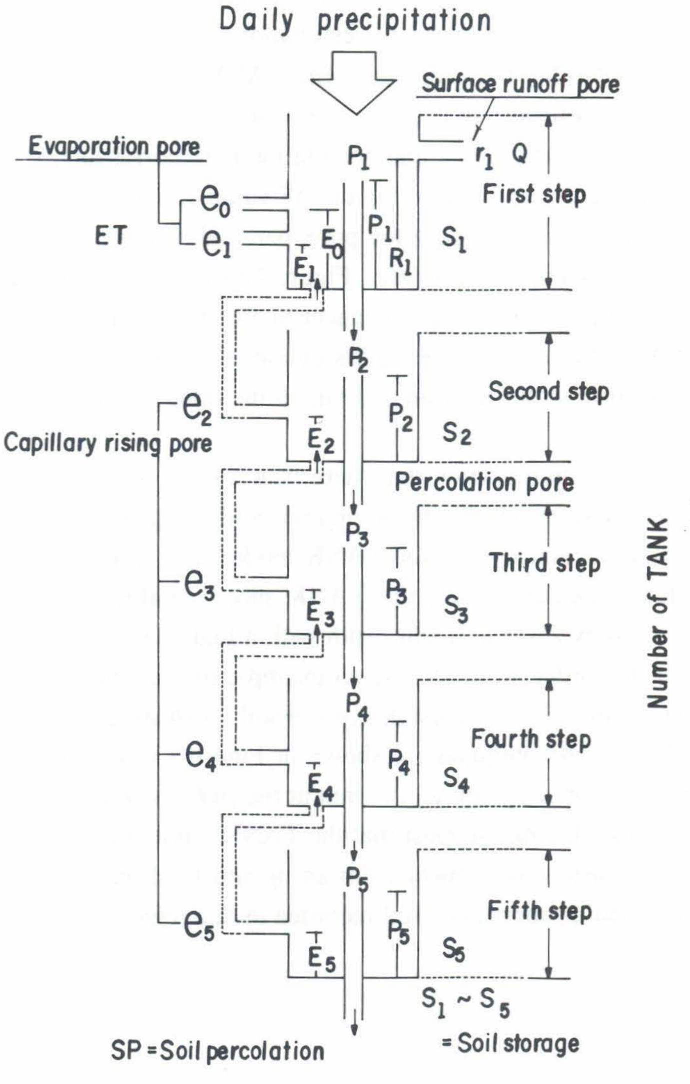

FIG. 8 - Schematic illustration of the "TANK"model.

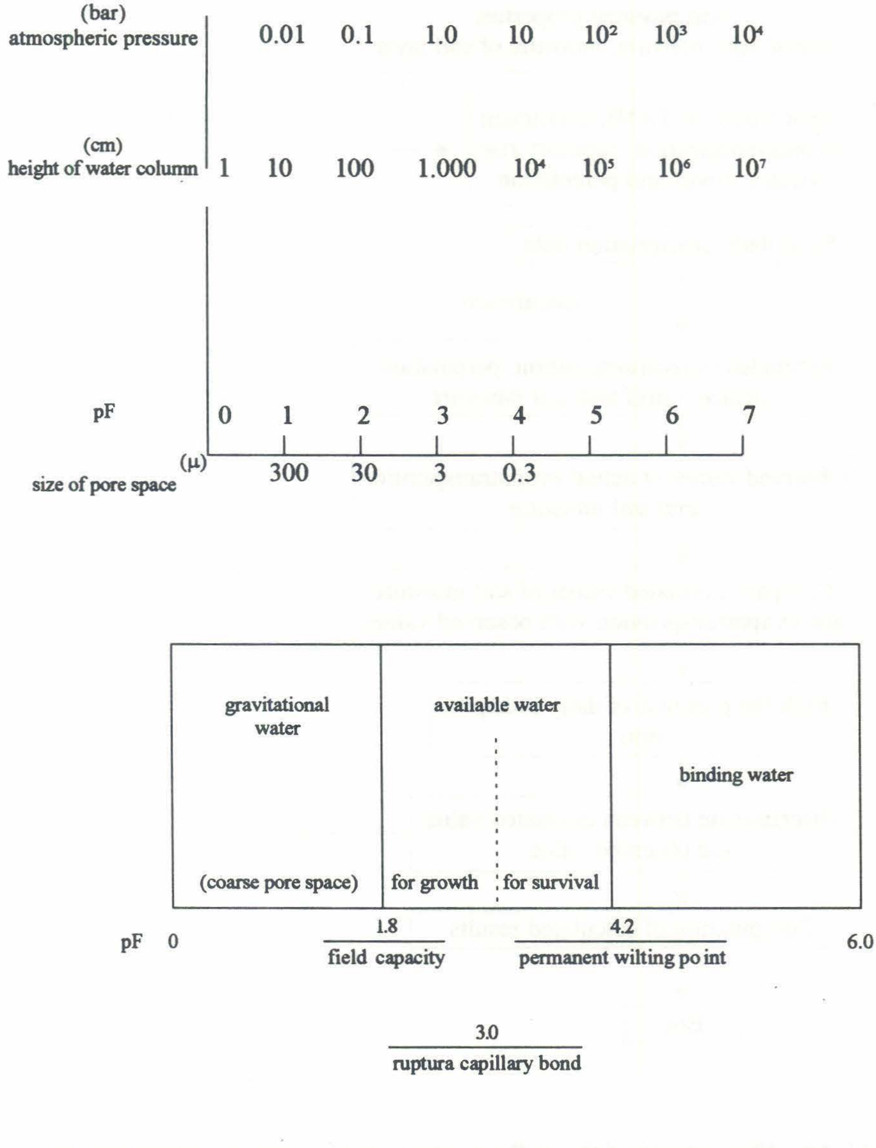

FIG. 9 - Physical theory of soil moisture (by Hayasaka).

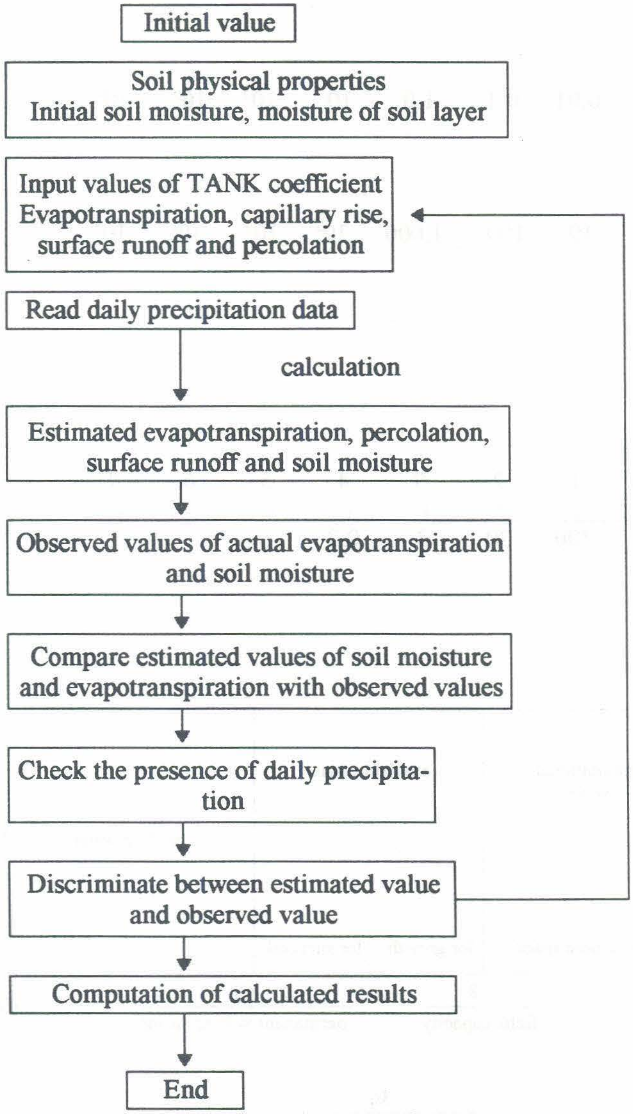

FIG. 10 - Flow chart of the soil moisture movement in cultivated upland field.

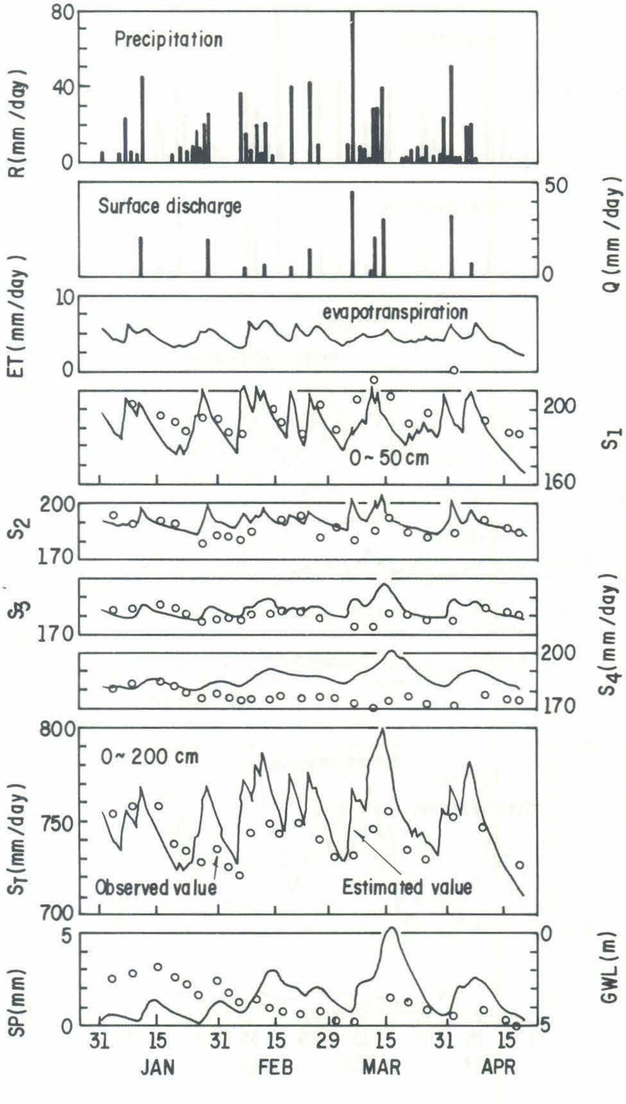

FIG. 11 - Comparison of estimated values of soil moisture, ground water level and evapotranspiration in Pit 1 with observed values.

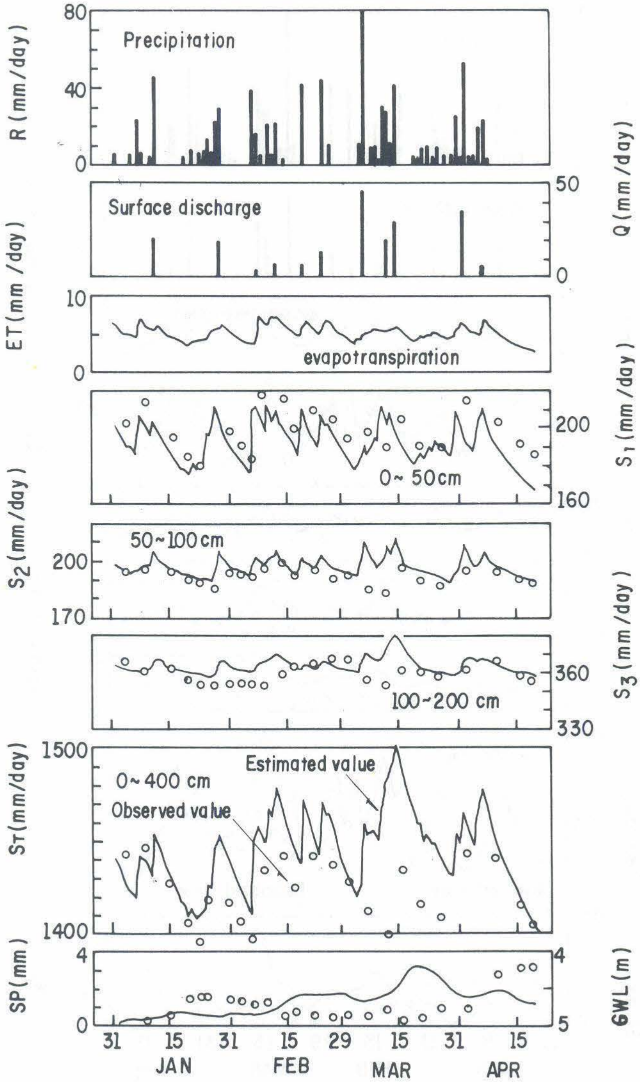

FIG. 12 - Comparison of estimated values of soil moisture, ground water level and evapotranspiration in Pit 2 with observed values.

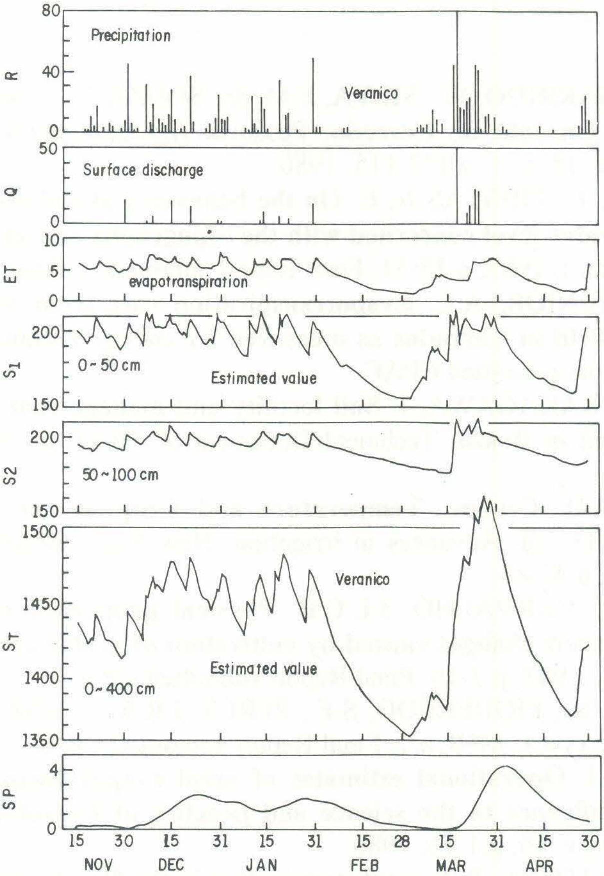

FIG. 13 - Seasonal variation of the soil moisture estimated during a long spell of Veranico in 1981.

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