

A climatological study of soil moisture under corn crop at Campina Grande (NE Brazil)

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सारा — इस शोध-पत्र में कॅम्पीना ग्रैंड (उत्तर पूर्वी ब्राजील) की मक्का की फसल में खेत की मिट्टी की नमी से संबंधित जलवायविक अध्ययन के परिणामों को प्रस्तुत किया गया है। 25 वर्ष की अवधि के दौरान फसल के बढ़ने के समय पाई गई नमी की मात्रा के दैनिक मानों का मूल्यांकन किया गया है। इस उद्देश्य के लिए छः क्षेत्रों वाले बहुमुखी मृदा नमी बजट मॉडल का प्रयोग किया गया है तथा एक से लेकर छः क्षेत्रों के लिए उपलब्ध जल क्षमता की क्रमशः लगभग 5, 7.5, 12.5, 25, 25 और 25% मात्रा मानी गयी है। पैदावार के विभिन्न स्तरों पर छः क्षेत्रों के लिए विभिन्न रूट सक्रियता गुणांक माने गए हैं तथा नमी की मात्रा पर इन गुणांकों की निर्भरता के संबंध में यहाँ विचार किया गया है। सभी मृदा क्षेत्रों में एक जैसी नमी मोचन विशेषताएँ पाई गई हैं। वर्षा ऋतु के दिनों में वापोत्सर्जन के कारण वर्षा से पूर्व आर्द्रता नमी के हास का पता चला है। इस अध्ययन में उपलब्ध जल क्षमता के चार मानों तथा मक्का की उपज की मार्च से सितम्बर के बीच की तीन अवधियों पर विचार किया गया है। दैनिक मृदा नमी आंकड़ा के लिए प्रथम कोटि के मार्कोव श्रृंखला मॉडल का प्रयोग किया गया है। इस स्थान पर मक्का की सबसे अधिक उपज की अवधि का पता लगाने के लिए मृदा नमी औसम और संभावनाओं का प्रयोग किया गया है। फसल के लिए सिंचाई की आवश्यकता की यहाँ संक्षेप में चर्चा की गई है।

ABSTRACT. Results of a climatological study of soil moisture under corn crop at Campina Grande (NE Brazil) are presented in this paper. Daily values of available moisture content during the crop growing period are evaluated for a period of 25 years. A six zone versatile soil moisture budget model is used for this purpose and approximately 5, 7.5, 12.5, 25, 25 and 25% of the available water capacity (AWC) are attributed to zones one to six respectively. Different root activity coefficients are assumed for the six zones in different growth stages and the dependence of these coefficients on moisture content is taken into consideration. The same moisture releasing characteristics are assumed for all soil zones. On rainy days moisture loss due to evapotranspiration is assumed to take place before precipitation. Four AWC values and three corn growing periods between March and September are considered in this study. A first order Markov chain model is applied to the daily soil moisture data. Soil moisture averages and probabilities are used to identify the optimum growing period for corn at this station. The irrigation requirements of the crop are briefly discussed.

Key words — Soil moisture, Soil zones, Available moisture content, Root zone.

1. Introduction

Soil moisture is an important parameter in agriculture, forestry and hydrology. It plays a significant role in plant growth, in determining crop yields and in the soil hydrological balance. Since it is impractical to measure soil moisture on the time and space scales required for agroclimatological studies, several models have been developed for its estimation (Thornthwaite and Mather 1955, Holmes and Robertson 1959, Baier and Robertson 1966, De Jong and Shaykewich 1981, Robertson 1985). The versatile soil moisture budget (VSMB) originally developed by Baier and Robertson (1966) takes into consideration the rooting depth of the crop, root concentration in different soil depths and the water holding and water release characteristics of each zone. The changes in root concentration as the crop develops towards maturity can be accounted for.

This study reports the soil moisture changes under corn at Campina Grande (7° 13'S, 35°53'W) a semi-arid station in Northeast (NE) Brazil. Campina Grande is situated 130 km from the Atlantic coast and receives an annual precipitation of 700 mm. Annual potential evapotranspiration is 1100 mm. The main crops grown are corn, rice, sugarcane and beans.

2. Methodology

In this study mean decadal (ten day periods) potential evapotranspiration (PE) values derived from Thornthwaite's procedure (Thornthwaite 1948, Thornthwaite and Mather 1955) are used to obtain daily PE values and these together with daily precipitation data are used to evaluate daily soil moisture values for a twenty-five year period. A VSMB model was used for this purpose. Values of 75, 100, 150 and 200 mm are assigned to the available water capacity (AWC) of the root zone of the soil which represents the difference between the field capacity and the permanent wilting point. The soil root depth is divided into six zones and approximately 5, 7.5, 12.5, 25, 25 and 25% of the AWC are attributed to the zones one to six respectively.

The contribution of each zone to the total actual evapotranspiration (AE) is evaluated from the following expression:

$$PAE_{(j,x)} = K_{ij} \left(\frac{WS_{(j,x-1)}}{WC_{(j)}} \right) Z_{jx} PE_{(x)} \quad (1)$$

where,

$PAE_{(j,x)}$ = partial evapotranspiration from the j th zone on day x

K_{ij} = crop coefficient for the j th zone in growth stage i

$WS_{(j,x-1)}$ = available moisture content of the j th zone at the end of day $(x-1)$

$WC_{(j)}$ = available moisture capacity of j th zone

$PE_{(x)}$ = potential evapotranspiration on day x

Z = factor depending on soil dryness characteristics

A set of 100 values between 0 and 1.0 are assigned to Z corresponding to 100 values between 0 and 1.0 of WS/WC on the assumption that the ratio AE/PE remains equal to unity until relative available moisture content WS/WC decreases to 0.7 and then decreases linearly with WS/WC . Such an assumption is a reasonable first approximation for most medium textured soils.

The K coefficients reflect the root activity at different depths during different growth stages of the crop. The corn crop growing period is divided into three principal stages and in each stage different K values are assigned to the six zones. When the upper zones of the soil are dry, relatively more moisture is removed from the lower zones than when the soil is uniformly wet. To take this aspect into consideration the K coefficients for each zone below the first are increased as a function of the moisture content of the respective upper zones.

$$K'_j = K_j + K_j \left[\sum_{m=1}^{j-1} K_m \left(1 - \frac{WS_m}{WC_m} \right) \right] \quad (2)$$

where,

K'_j = adjusted K coefficient for the j th zone

WS_m = available moisture content in the m th zone

WC_m = available moisture capacity of the m th zone

The available moisture content and the moisture loss from each zone are obtained from the following expressions :

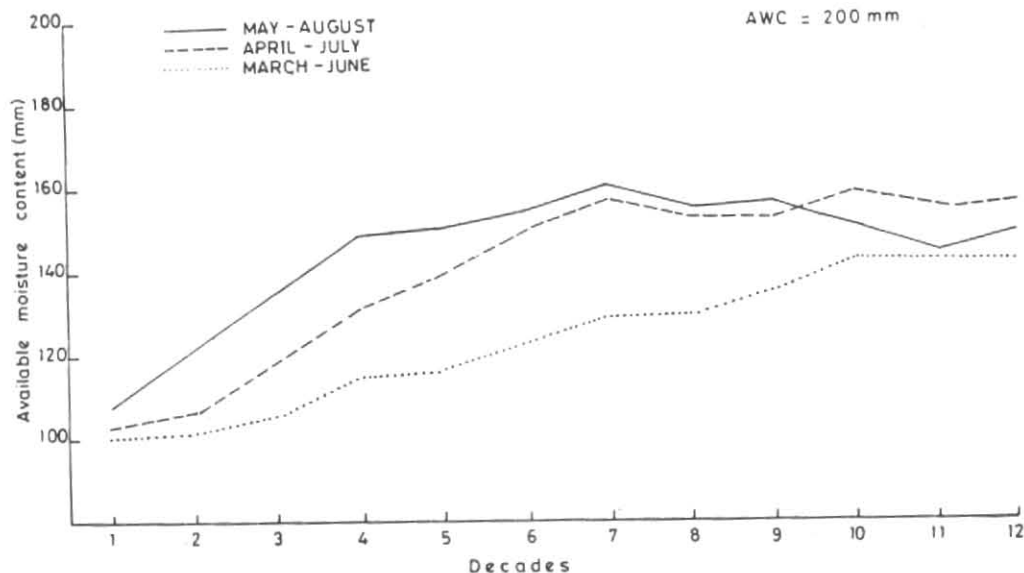


Fig. 1. Mean available moisture content in different corn growing periods

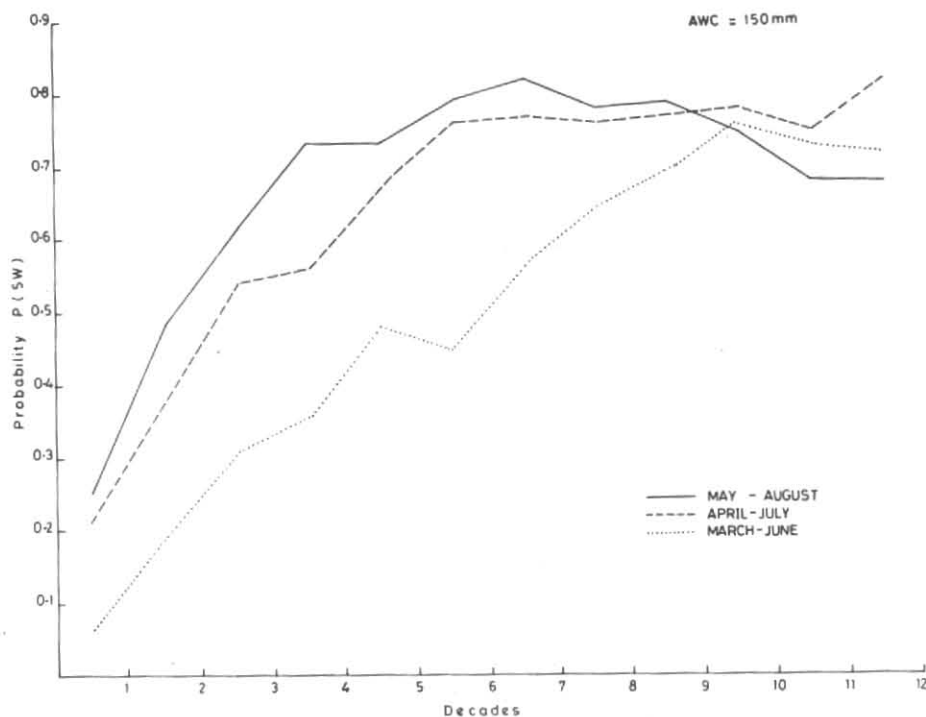


Fig. 2. Probability of atleast five consecutive days per decade with wet soil P(5W) in different periods.

$$WS_{(j, x)} = WS_{(j, x - 1)} - PAE_{(j, x)} \quad (3)$$

$$AE_{(j, x)} = PAE_{(j, x)} \text{ if } PAE_{(j, x)} \leq WS_{(j, x-1)} \quad (5)$$

$$WS_{(j, x)} = 0 \text{ if } PAE_{(j, x)} > WS_{(j, x - 1)} \quad (4)$$

$$AE_{(j, x)} = WS_{(j, x - 1)} \text{ if } PAE_{(j, x)} > WS_{(j, x - 1)} \quad (6)$$

where, $WS_{(j, x)}$ is the available moisture in the j th zone at the end of day x .

TABLE 1
Estimated soil water content (mm) exceeded at given probabilities

Decade	March-June			April-July			May-August		
	Probability (%)			Probability (%)			Probability (%)		
	25	50	75	25	50	75	25	50	75
1	98	94	89	110	98	93	112	101	96
2	122	85	79	125	106	85	147	110	94
3	131	89	74	138	114	91	177	129	96
4	149	96	80	172	132	99	190	151	111
5	149	109	73	179	144	105	191	165	109
6	169	105	84	187	162	118	196	176	111
7	168	120	87	192	164	141	196	174	124
8	164	132	94	188	172	126	189	171	123
9	169	138	102	189	169	132	186	168	132
10	176	145	126	196	178	138	175	158	142
11	182	148	115	190	174	129	174	151	125
12	187	144	104	187	166	146	175	142	121

Available water capacity = 200 mm

The sum of $AE_{(j, x)}$ for the six zones gives the actual evapotranspiration (AE) on day x . The sum of $WS_{(j, x)}$ for the six zones represents the available moisture content of the root zone of the soil on day x if no precipitation occurs on that day. If precipitation occurs, the values of $WS_{(j, x)}$ for some or all the six zones may increase.

On days with precipitation it is assumed that moisture loss due to evapotranspiration occurs before precipitation. Precipitation enters the first zone and if this zone reaches its moisture holding capacity the excess water enters the second zone and so on. Excess water leaving the sixth zone is considered the water surplus on that day.

In each year the computations are carried out for the four month corn growing period for the four AWC values assumed. Three corn growing periods, March-June, April-July and May-August are considered in this study. Approximately 80% of the annual precipitation at Campina Grande is received during the months March to August.

Each month is divided into three decades, the last

decade having 8, 9, 10 or 11 days depending on the month. Based on the daily soil moisture data for 25 years mean decadal available moisture contents are obtained. A first order Markov chain model is applied to the daily soil moisture data and the initial and conditional probabilities of dry and wet days are computed. The critical moisture content separating a wet day from a dry day is taken to be half the AWC assumed. For each decade during the growing period the probability of occurrence of five consecutive wet days, $P(5W)$ is evaluated using the above probabilities.

The soil moisture model described above is also used to evaluate the irrigation needs for corn crop at Campina Grande. The computations for available water capacities of 100 and 200 mm are repeated with the modification that each time the available moisture content decreases to a predetermined value the moisture content on that day is replaced with that corresponding to 95% of the AWC. In practical terms this means that each time the soil moisture is depleted to a preselected value, irrigation is applied to bring it back to a safe level. This part of the study is carried out assuming three critical moisture levels (55, 70 and 85% of the AWC). The number of irrigation applications during the four month growing period and the mean interval between irrigations are obtained for each year of the study period and from these mean values for the 25-year period are derived.

3. Results and discussion

Mean decadal values of available moisture content are evaluated for different growing periods for the four AWC values considered (Fig. 1). An interesting feature noticed is that in general the available moisture content as a fraction of AWC decreases with an increase in AWC value from 75 to 200 mm. During the period May-August available moisture content was almost always more than 50% of the AWC for all the four AWC values even though the climatic water balance based on Thornthwaite's procedure (Thornthwaite 1948, Thornthwaite and Mather 1955) shows large water deficiency during the months August and September. Based on mean decadal values of available moisture content the period May-August is found to be the most suitable for the growth of corn crop at this station.

The probability of occurrence of five consecutive wet days, $P(5W)$, are evaluated for each of the twelve decades in successive four month periods (Fig. 2). The results once again indicate that the period May-August

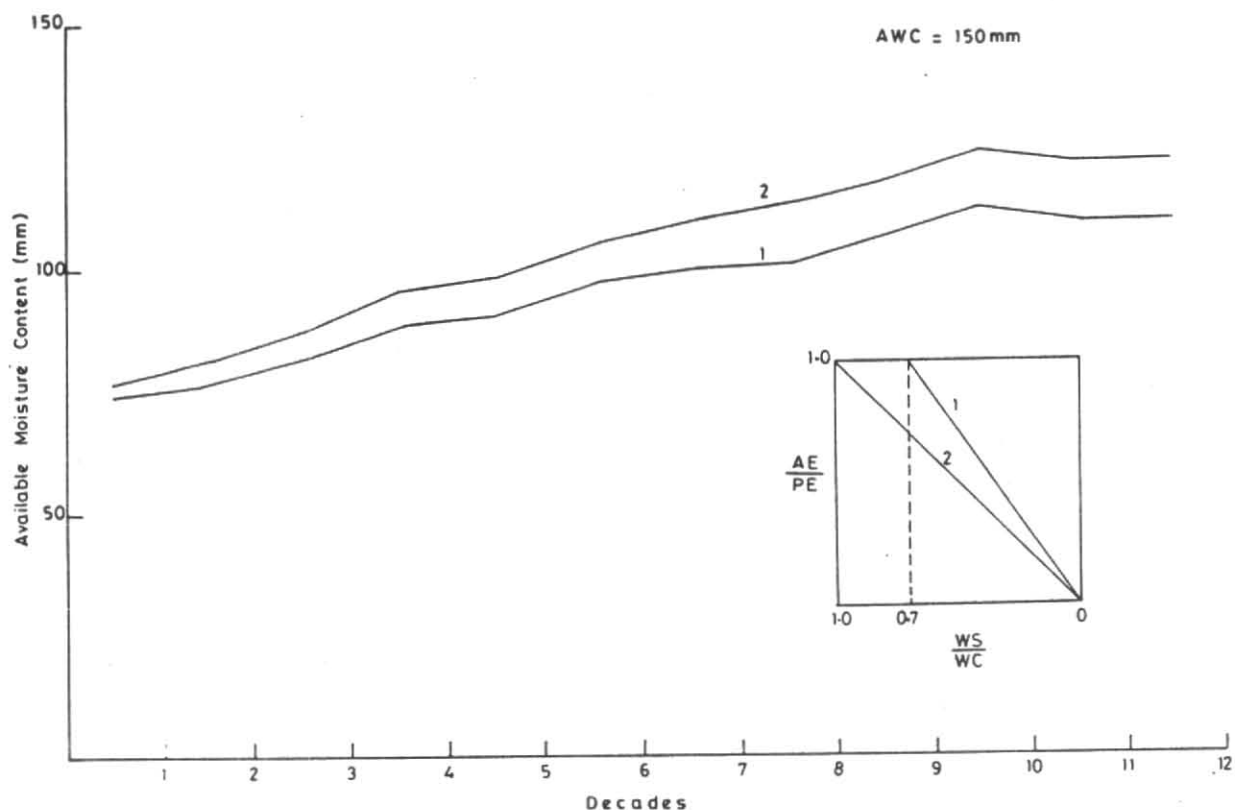


Fig. 3. Long term mean available moisture content during the period March-June based on two relationships between $\frac{AE}{PE}$ and $\frac{WS}{WC}$

TABLE 2

Irrigation requirements for corn crop at Campina Grande

Available water capacity (mm)	Limiting soil moisture value (mm)	Number of irrigations	Mean interval between irrigations (days)	Number of days with available soil moisture content			Irrigation need (mm)	Water surplus (mm)
				85-90 mm	90-95 mm	95-100 mm		
100	85	12	11	33	42	47	120	192
				170-180 mm 180-190 mm 190-200 mm				
200	170	4	41	26	46	50	80	146

is the best of three growing periods considered. The same conclusion is arrived at on the basis of the available moisture content exceeded at different probability levels (Table 1).

Decadal values of AE for the months May-August during the 25-year period for different AWC values are compared with corresponding PE values. During May and June AE is considerably less than PE, while

during July and August AE is almost always greater than PE, the ratio between the two parameters varying between 1.0 and 1.2. The sum of the K coefficients for the six soil zones is more than unity during July and August and the moisture content of the upper soil zones is quite high and hence AE exceeds PE in these months.

Irrigation requirements are evaluated for the period May-August assuming two values of AWC (100 and 200 mm) and three critical moisture levels (55, 70 and 85% AWC).

It is found that to maintain similar moisture conditions in the soil more irrigation water is necessary in the case of AWC₁₀₀ than for AWC₂₀₀. Similar result was obtained by De Jong (1985). A summary of the results for the 85% moisture level is given in Table 2.

According to Yao (1974), for the optimum growth of corn crop, the available moisture content should be maintained above 85% of the AWC. The results of the present study suggest that even during the optimum growing period for corn at Campina Grande (May-August) significant amount of supplementary irrigation is necessary. In the case of AWC₁₀₀ the total water received by the crop (precipitation plus irrigation) is more and the moisture holding capacity of the root zone less than in the case of AWC₂₀₀ and hence water surplus for AWC₁₀₀ is more than for AWC₂₀₀.

Denmead and Shaw (1962) found a linear relationship between WS/AWC and AE/PE in a corn field under conditions of high PE rates. Several researchers have found a linear relationship in their experiments under a variety of climates and crop and soil conditions (Gardner and Ehlig 1963, Smith 1959). Assumption of such a relationship between WS/AWC and AE/PE in the present model requires the use of $Z = I$ for all values of WS/AWC.

Calculations of available moisture content during the period March to June for AWC₁₅₀ are repeated with this modification and the mean decadal values of available moisture content obtained are compared with those based on the use of Z values mentioned earlier (Fig. 3). The two corresponding relationships between AE/PE and WS/AWC are also included in Fig. 3. The difference between the two curves representing mean values for 25 years are significant and differences in individual years are quite pronounced. Much controversy surrounds the relationship between

WS/AWC and AE/PE (Robertson 1977). Comparison of the results obtained from the use of various relationships between the two parameters proposed in the past (Veihmeyer 1956, Richards and Richards 1957, Slatyer 1956, Fitzpatrick *et al.* 1967, Gardner 1960) with measured soil moisture data is necessary for the proper use of soil moisture models.

References

- Baier, W. and Robertson, G.W., 1966, "A new versatile soil moisture budget", *Can. J. Plant. Sci.*, **46**, 299-315.
- De Jong, R. and Shaykewich, C.F., 1981, "A soil water budget model with a nearly impermeable layer", *Can. J. Soil Sci.*, **61**, 361-371.
- De Jong, R., 1985, "Soil water modelling using daily and mean-daily data derived from historical monthly values", *Atmosphere-Ocean*, **23**, 3, 254-266.
- Denmead, O.T. and Shaw, R.H., 1962, "Availability of soil water to plants as affected by soil moisture content and meteorological conditions", *Agron. J.*, **54**, 385-390.
- Fitzpatrick, E.A., Slatyer, R.O. and Krishnan, A.I., 1967, "Incidence and duration of periods of plant growth in Central Australia as estimated from climatic data", *Agric. Meteorol.*, **4**, 398-404.
- Gardner, W.R. and Ehlig, C.F., 1963, "The influence of soil water on transpiration by plants", *J. Geophys. Res.*, **68**, 5719-5724.
- Gardner, W.R., 1960, "Dynamic aspects of water availability to plants", *Soil Sci.*, **89**, 63-73.
- Holmes, R.M. and Robertson, 1959, "A modulated soil moisture budget", *Mon. Wea. Rev.*, **87**, 101-106.
- Richards, L.A. and Richards, S.J., 1957, "Soil moisture, In soil, 1957 Year Book of Agriculture", U.S. Dept. Agric., Washington, D.C., 49-60.
- Robertson, G.W., 1977, "A versatile soil water budget for drought prone regions and dryland farming areas in India", FAO/TF/IND/136, Hyderabad (India)
- Robertson, G.W., 1985, "Multiple-crop multiple-layer soil-water budget: a computer program documentation", Supply and Services Canada, Ottawa, 41 p.
- Slatyer, R.O., 1956, "Evapotranspiration in relation to soil moisture", *Neth. J. Agric. Sci.*, **4**, 1, 73-76.
- Smith, G.W., 1959, "The determination of soil moisture under a permanent grass cover", *J. Geophys. Res.*, **64**, 477-483.
- Thomthwaite, C.W., 1948, "An approach toward a rational classification of climate", *Geogr. Rev.*, **38**, 85-94.
- Thomthwaite, C.W. and Mather, J.R., 1955, "The Water Balance", Climatology VIII (1), Drexel Inst. of Technol., N.J., 104 p.
- Veihmeyer, F.J., 1956, "Soil Moisture", In Encyclopedia of Plant Physiology 3, Water relations of plants, Springer Verlag, Berlin, 61-123.
- Yao, A.Y.M., 1974, "Agricultural potential estimated from the ratio of actual to potential evapotranspiration", *Agric. Meteorol.*, **13**, 405-417.