

Soil Moisture Prediction Under Maize in Sandy Loam

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Abstract: Soil-Plant-Atmosphere-Water (SPA-W) model has been used to provide dynamic soil water estimates under irrigated maize at Delhi for six years, 1985 to 1991, excepting 1987. Simulated soil moisture values are compared with gravimetrically observed data for three layers, viz., 0-2.5 cm, 2.5-30 cm and 30-60 cm. Simulated runs mimic the observed fluctuations and trend in moisture content of different layers of soil profile. Deeper soil layers exhibit better agreement between simulated and measured soil moisture content compared to skin layer of profile. Output from six runs were used to make comparisons at 40 points for each layer. Correlations with standard errors (cm) for first three layers are 0.59 (0.3), 0.62 (1.3) and 0.62 (1.1), respectively. For underlining the utility for model for irrigation scheduling in real time, observed and simulated values (integrated up to 60 cm depth) were pooled for six years. High correlation coefficient (0.89) was observed with SE 1.0 cm. The results established the usefulness of model in irrigation scheduling for maize crop by predicting moisture content.

Key words: Maize, soil moisture prediction, SPA-W model.

Soil water distribution in the earth's upper mantle is of great importance in the field of agriculture owing to its operational applications in irrigation management. Soil moisture estimates integrate soil-plant-atmosphere effects and are valuable for determining the effects of climatic variability on crop growth and production. Soil moisture estimation is an integral part of any water balance scheme. As the conventional methods of soil moisture estimation are very tedious and time consuming, simulation models have been developed and applied in recent years (Baier and Robertson, 1966; Ritchie, 1972; Saxton and Bluhm, 1982; Ritchie, 1985). These models accurately simulate the several physical processes in the soil-plant-atmosphere system in order

to determine the dynamic state of soil water. However, some of the models have a very wide range of detail and complexity, depending upon the inputs available and the crops to be considered, which may lead to limited operational utility. The SPA-W model developed by Saxton (1989) is based on readily available inputs such as precipitation, pan evaporation, crop and soil characteristics, and are widely used as compared to other specified models. Earlier studies on SPA-W model have proven its applicability to various crops like wheat, sorghum, soybeans, corn and brome grass (Sudar *et al.*, 1981; Saxton and Bluhm, 1982; Koelliker *et al.*, 1976; Saxton, 1983). This model has been successfully used in a tropical semi-arid region by Omer *et*

al. (1988). The objective of this paper is to simulate soil moisture by SPAW model for irrigation scheduling. An attempt is made to calibrate this model and also to compute the vertical distribution of soil moisture under maize crop for sandy loam soils.

Materials and Methods

Model procedures

The SPAW model describes vertical soil water budget on daily basis by integrating and relating the plant-soil-atmosphere processes with minimal requirements of daily inputs consisting of routinely measured weather data. The driving force in this model is daily potential evapotranspiration (ET), which is determined on the basis of maximum energy available for liquid to vapor phase change (water loss). Calculated potential ET is then reduced to estimate actual ET by giving due consideration to soil, crop and weather conditions. Intermediate computations using the per cent ground shading, transpirability curve and rooting patterns divide the actual ET into principal components of interception evaporation, soil water evaporation and plant transpiration. Actual ET is subtracted from existing soil moisture to estimate layer wise moisture status. Free water input at soil surface through rainfall or irrigation is reduced by runoff amount (computed by SCS-CN method) before infiltration. After replenishing the soil moisture of each layer, excess water is lost as deep percolation. Darcy's equation is utilized to provide a more realistic soil water flow within the profile depth and layer wise soil moisture is redistributed to arrive at final soil moisture status. Saxton (1983) has described the

model physics in detail with input and output requirements.

Model application assumes horizontally homogeneous plant soil atmosphere conditions represented by model parameters and data. Daily infiltration is assumed to occur instantaneously. No diurnal patterns of soil water, heat or ET are considered even though they occur. Parameterized water extraction patterns are not influenced by water stress.

Materials

To calibrate and test accuracy and applicability of the SPAW model, the research data were obtained from research farm at Indian Agricultural Research Institute, New Delhi. Daily precipitation and pan evaporation for the test site for six crop seasons (1985, 1986 and 1988 to 1991) were used along with a generalized parameter set representing the crop and soil characteristics. Table 1 provides inputs on the crop varieties, cumulative rainfall and evapotranspiration over whole crop duration for all the six years. Simulation of moisture content of 150 cm deep soil profile for six crop seasons of maize was made on daily basis. Simulated moisture values were compared with weekly measured data for 0-2.5, 2.5-30 and 30-60 cm soil depths. Vertical distribution of layer wise soil moisture content, for both simulated as well as observed values, was plotted for different years.

Crop data

Maize was selected because of its economic importance and susceptibility to water stress. In order to calibrate the model with

Table 1. Crop summary for growing seasons

Year	Variety	Date of sowing	Crop duration (days)	Cumulative rainfall (cm)	Cumulative ET	
					Observed (cm)	Simulated (cm)
1985	Ganga SF-2	July 18	89	40.3	29.2	32.4
1986	Ganga SF-5	July 15	96	19.4	31.1	30.7
1988	Ganga SF-2	July 12	102	76.7	37.6	36.0
1989	EH-40084	July 19	71	14.8	28.6	27.1
1990	Ganga SF-2	July 12	106	56.7	40.3	34.8
1991	Ganga SF-2	July 25	87	23.5	22.1	25.0

data from research plots, information on crop canopy (soil shading percentage) and crop phenology given in Fig. 1, plant water extraction pattern by root distribution values throughout the soil profile at selected time intervals, susceptibility curves and plant's ability to extract soil moisture are

Soil data

The soil profile was represented by six layers with depth of 2.5, 30, 60, 90, 120 and 150 cm. Observed soil data on its mechanical composition and water retention characteristics was obtained from WTC, IARI, New Delhi. The soil is composed

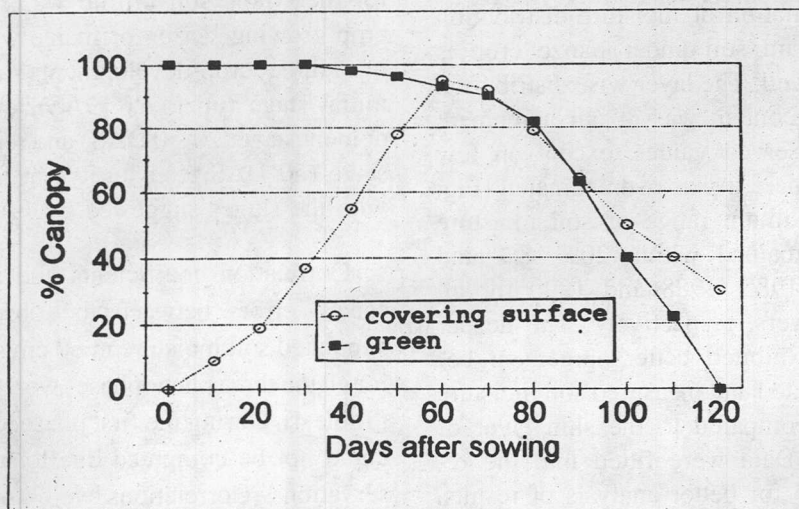


Fig. 1. Layer wise observed and simulated soil moisture under maize.

required as general inputs. Distribution of water extraction from the soil layers representing the water uptake by roots is given in Table 2.

of 70% sand and 20% clay with 13.1%, 21.9% and 44.7% wilting point, field capacity and saturation values, respectively. Modified version of the Soil Conservation

Table 2. Water extraction (%) from the soil layers

Depth of soil layer (cm)	Days after sowing					
	16	22	30	38	46	54
0-2.5*	0	0	0	0	0	0
2.5-30	100	90	82	77	72	70
30-60	0	10	14	18	20	20
60-90	0	0	4	5	8	9
90-120	0	0	0	0	0	1
120-150**	0	0	0	0	0	0

* Evaporative layer. ** Image layer.

Service (SCS), Curve Number (CN) method was used for the estimation of runoff on daily basis. Input data on irrigation type, date and amount were also obtained from WTC, IARI, New Delhi.

Results and Discussion

Layer wise soil moisture content

The simulation of moisture distribution in sandy loam soil under maize crop is reasonably well. The layer wise distribution of moisture content was in fair agreement with the observed values, except on few occasions where it was overestimated (Fig. 2). The maximum range of soil moisture variation remained within 20%, 8% and 6% during 1985, 1988 and 1990 for all the three layers, respectively. The deeper soil layer exhibited better agreement between simulated and measured soil moisture content as compared to the skin layer of the profile. Data were fitted into the regression line for better analysis of results. Correlation coefficient for simulated and

measured soil moisture content for layer 1, 2 and 3 was 0.59 (0.3), 0.62 (1.3), 0.62 (1.1), respectively (Table 3).

Phenophase-wise soil moisture content in profile

A detailed phase-wise comparison between simulated and observed soil moisture for the whole soil profile was made. The crop growing season of maize was divided into three crop-development stages, viz., initial stage (up to 20 DAS), crop development stage (20-50 DAS) and reproductive stage (50 DAS to maturity) in accordance with the stages suggested by FAO (1977).

Correlation coefficients and root mean square errors between the observed and simulated soil moisture in 60 cm soil profile for all the three phenophases were calculated (Table 4). During the first phase, correlation could not be computed due to lack of observations. Correlations were found to be 0.59 and 0.62 during the second and third

Table 3. Observed and simulated soil moisture (cm) in different layers

Layer	RMSE (cm)	CC	Regression equation
0-2.5 cm	0.3	0.59	$Y = 1.62 + 0.88 X$
2.5-30 cm	1.3	0.62	$Y = 23.38 + 0.66 X$
30-60 cm	1.1	0.62	$Y = 22.06 + 0.69 X$

SOIL MOISTURE PREDICTION

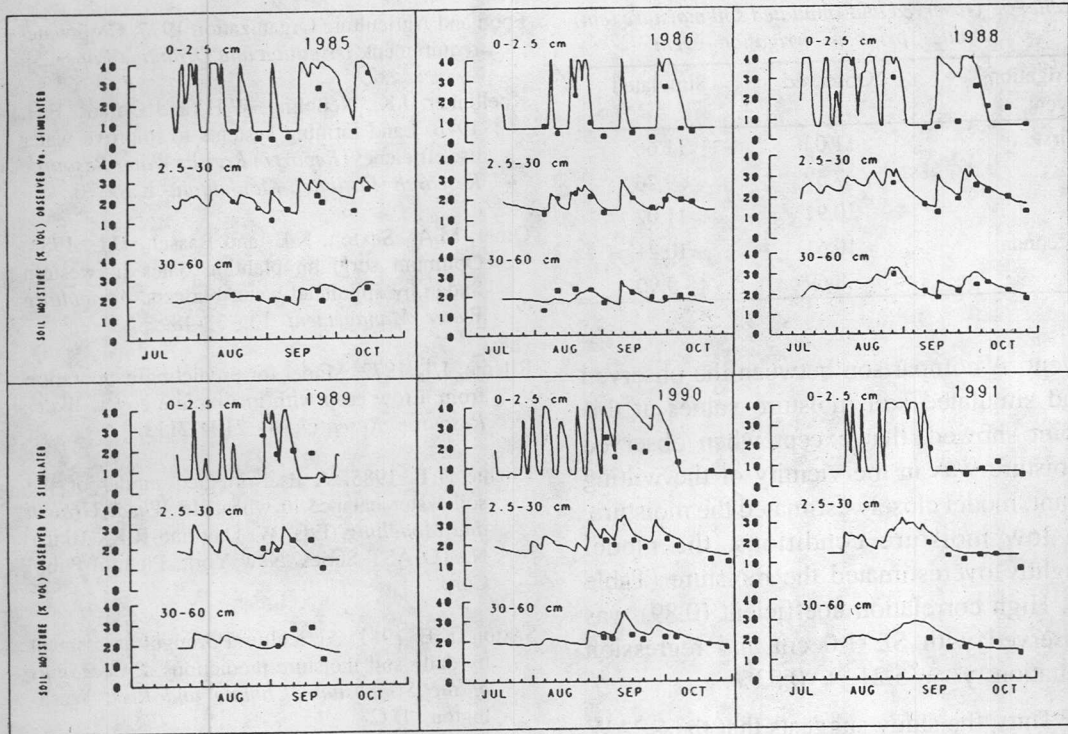


Fig. 2. Scatter plots of observed and simulated soil moisture for different layers.

phase, respectively. Figure 2 provides support to this analysis, which shows that the simulated values, during crop development stage (21-50 DAS) and reproductive stage (51-90 DAS), are close to the observed data points in all the years. Highly significant correlation coefficients (0.86 and 0.93) were found at the end of both the phases corresponding to 50 DAS and 90 DAS, respectively, indicating better model performance for this period.

Irrigation scheduling

In order to determine the utility of the model for irrigation scheduling, total irrigation events, along with the observed and simulated soil moisture values integrated up to 60 cm depth were determined for all the years. Maximum number of irrigations made in any year was two. The model would be in a position to predict the dates of irrigation, if it is able to simulate the soil moisture just before the irrigation

Table 4. Observed and simulated soil moisture in 60 cm soil profile at development and reproduction stages

Phenophases (Days after sowing)	RMSE (cm)	CC	Regression equation
Development stage (20-50)	2.2	0.59	$Y=42.80+0.72X$
Reproductive stage (51-90)	2.7	0.62	$Y=44.7+0.71X$

Table 5. Observed and simulated soil moisture (cm) values prior to irrigation event

Irrigation event	Observed	Simulated
First	11.03	11.66
	7.52	9.26
	10.91	11.02
Second	10.61	10.21
	8.69	9.90

event. A comparison between the observed and simulated soil moisture values at this point showed, that except when observed moisture was in the vicinity of the wilting point, model closely estimated the moisture. In low moisture conditions, the model slightly overestimated the moisture (Table 5). High correlation coefficient (0.89) was observed with SE 1.0 cm and regression equation $y = 5.21 + 0.53x$.

Thus, the study suggests that the SPAW model could be successfully used for irrigation scheduling for maize crop by simulating the moisture content of the whole soil profile.

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