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Comparative evaluation of different soil water balance models in the estimation of root zone soil moisture

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ABSTRACT

Four soil water balance models viz., Thornthwaite and Mather, FAO, Rijtema and Aboukhaled and Rijks were modified for root zone extension and runoff to simulate the profile soil moisture fluctuations on a daily basis in an agricultural field with respect to soil characteristics and land use pattern under rainfed conditions. Daily rainfall was used as model input. Instantaneous uniform redistribution of soil moisture in the effective root zone and negligible contribution of soil water through upward flux was assumed. To evaluate model performance, observed values of soil moisture were taken under chickpea *(Cicer arietinum L.)* in the Jagat (clay loam texture) and Holambi (loam texture) soil series under rainfed conditions in the experimental farm of Indian Agricultural Research Institute, New Delhi. The r^2 and D-index values indicate that both Rijks and Rijtema and Aboukhaled models are at par and better than other two models.

Key words: Model comparison, Evapotranspiration, D-index

For optimum crop production, the basic requirement in agricultural planning is to draw up the best possible cropping system to match the meteorological conditions most frequently realised at a given location. Besides information on rainfall at a place, it is necessary to estimate the extent to which the rainfall is able to meet the transpiration needs of the crops and the evaporative losses from the soil. This is most conveniently done by soil water balance models developed in recent years which range in complexity from simple book keeping methods such as that of Thornthwaite and Mather (1955), Baier *et al.* (1972), Victor (1984), Rao (1987), Campbell and Diaz (1988) and Mandal *et al.* (2002) to process based models such as those described by Norman and Campbell (1983), Retta and Hanks (1981), Ritchie (1972), Saxton *et al.* (1974), Hayhoe and DeJong (1982), Bhattacharya and Sastry (1999), Stockle and Campbell (1985) and Stockle (1985). The simple book keeping procedures require data of soil water storage properties namely the field capacity (FC) and permanent wilting point (PWP); despite some limitations (Hillel, 1980), they are acceptable for practical soil water simulations. Process based models need data of soil water storage properties as well as transmission characteristics (e.g. soil hydraulic conductivity vs. soil moisture content relationship). Therefore, simple water balance models are preferred in field applications and large area studies (Rao, 1998).

In this study, four simple soil water balance models namely Thornthwaite and Mather (1955), FAO (Frere and Popov, 1979), Rijtema and Aboukhaled, 1975 (Doorenbos and Kassam, 1979) and Rijks, 1981 (Oldeman and Frere, 1982) were used to monitor the daily root zone soil moisture content after they are modified for root zone extension and run off and testing these models by comparing with observed root zone soil moisture under chickpea (gram) at the field level.

MATERIALS AND METHODS

Conceptual soil water balance model

The soil water balance includes runoff, infiltration of rainfall into the soil, redistribution of infiltrated water within the root zone, evapotranspiration (ET) and percolation below the root zone. However, for purposes of computing daily water balance, instead of taking a constant depth throughout the growing season, the soil reservoir was considered to consist of two time variant compartments - an active layer of depth in which roots are present at any given time and from which both moisture extraction and drainage would occur and immediately below this, a passive layer of depth (maximum root depth - root depth attained any day after sowing) from which only drainage would occur. The two layers are distinct in the initial phase of crop growth and their relative depths are governed by the rate of root growth. But once the maximum root depth is attained, the entire soil reservoir becomes only one layer.

It is assumed that effective rainfall (rainfall - runoff) on any day is redistributed instantaneously (without any time lag) and uniformly over the root zone. The rainfall in excess of field capacity (FC) percolate to the lower passive zone and is instantaneously redistributed in that zone. The remaining water in excess of field capacity of passive zone moves out of it as deep percolation. The contribution to soil moisture from upward flux is not considered in these models. Details of the procedure adopted for evaluating the different components of water balance are described below.

Two layer model

For layer one (active root zone), the soil moisture content at the end of any day (t) can be estimated by the following daily soil water balance equation;

$$MC_1(t) = MC_1(t-1) + ISM(t) + R(t) - Q(t) - ET(t) - P_1(t) \qquad (1)$$

$$P_1(t) = 0 \quad \text{if } MC_1(t-1)+ISM(t)+R(t)-Q(t)-ET(t) \leq K_1(t) \qquad (2)$$

$$P_1(t) = MC_1(t-1)+ISM(t)+R(t)-Q(t)-ET(t)-K_1(t); \text{ otherwise} \qquad (3)$$

where,

MC_1 = soil moisture content in ayer1(mm)

R = rainfall (mm)

Q = runoff (mm)

ISM = incremental soil moisture due to daily root extension (mm)
ET = evapo transpiration (mm)
P_1 = percolation out of layer 1 (mm)
K_1 = available water holding capacity (FC-PWP) of layer 1 (mm)

Flow relationships for layer 2 (passive layer) are similar to that for layer 1 except that there is no ET loss from layer 2. Layer 1 has priority for recharge. This is expressed as follows;

$$MC_2(t) = MC_2(t\text{-}1) - ISM(t) + P_1(t) - P_2(t) \quad (4)$$

$$P_2(t) = 0, \text{ if } MC_2(t\text{-}1) - ISM(t) + P_1(t) \leq K_2(t) \quad (5)$$

$$P_2(t) = MC_2(t\text{-}1) - ISM(t) + P1(t) - K_2(t); \text{ otherwise} \quad (6)$$

where,
MC_2 = soil moisture content in layer 2 (mm)
P_2 = deep drainage out of layer 2 (mm)
K_2 is available water holding capacity of the layer 2 (mm).

Root growth model

Root depth of the crop increase with time. The Borg and Grimes (1986) root growth model is used to determine the root depth.

$$RD(t) = RDM[0.5 + 0.5\ \sin(3.03DAS / DTM - 1.47)] \quad (7)$$

where
RD = root depth (mm) attained at any day after sowing (DAS)
RDM = maximum root depth (mm)
DTM = DAS to maximum root depth (mm)

Sine value is in radians.

The minimum value of RD was set equal to 150 mm according to the assumption that soil evaporation would take place from top 150 mm of soil profile. The rooting depth is assumed to remain constant after it attained maximum depth. Thus, while the root zone is extending downwards, the soil depth, and consequently, the available water holding capacity of layer 1 increase in proportion to the increment in the root depth with a corresponding increase in the soil moisture content; the capacity and soil moisture contents of layer 2 decrease by an equivalent amount.

Available water holding capacity for layer 1 is given as

$$K_1(t) = K_1(t\text{-}1) + \frac{K_2(t\text{-}1) \times DRD}{(RDM - RD(t))} \quad (8)$$

where,

DRD = daily increase in root depth (mm)

$$DRD = RD(t) - RD(t\text{-}1) \quad (9)$$

Available water holding capacity of layer 2 is given as

$$K_2(t) = K_2(t\text{-}1) - K_1(t) + K_1(t\text{-}1) \quad (10)$$

Daily increment in soil moisture (ISM) gained through root extension is given by :

$$ISM(t) = \frac{MC_2(t\text{-}1) \times DRD}{(RDM - RD(t))} \quad (11)$$

Runoff model

Daily runoff (Q, mm) is estimated from

daily rainfall using the curve number (CN) technique of the soil conservation service (USDA, 1972) adapted for conditions in India [Ministry of Agriculture, 1972, Sahu (1990)] and combined with the soil moisture accounting procedure suggested by Sharply and Williams (1990). Details of runoff estimation are given below:

The CN method defines a retention parameter S (mm) which varies with time because of changes in soil moisture content. The parameter S is related to CN by the relationship.

$$S = 254\ (100 / CN - 1) \qquad (12)$$

The value of CN varies with antecedent moisture conditions (AMC). In the original procedure of USDA and its Indian adaptation, three such conditions are defined as AMCI, AMCII and AMCIII corresponding to dry, average and wet moisture conditions respectively. These conditions are identified empirically based on the cumulative rainfall in the 5 days preceding the current rainfall event for the growing season. Two limiting values of the cumulative rainfall of the previous 5 days are defined for identifying the AMC. If the rainfall is < 35.6 mm, then AMCI applies; if it is more than 53.3 mm AMCIII applies and if it is in between, AMCII applies.

The values of CN for average AMC (CN for AMCII or CN = CN2) are tabulated for various soil, land use and management conditions by the Ministry of Agriculture (1972). The corresponding values of CN for dry (CN1) and wet (CN3) catchment conditions are given by

$$CN1 = CN2 - \{20(100 - CN2)/[100 - CN2 + \exp(2.533 - 0.0636(100 - CN2))]\} \qquad (13)$$

$$CN3 = CN2 \exp[0.00673(100 - CN2)] \qquad (14)$$

For Indian conditions, Ministry of Agriculture (1972), the Government of India and Sahu (1990) reported the following modification for runoff estimation with respect to the soil type: for soil regions of India except for the black soil region with AMCII and AMCIII conditions

$$Q = \frac{(R) - 0.3S)^2}{(R + 0.7S)},\ \text{if } R > 0.3S \qquad (15)$$

$$Q = 0,\ \text{if } R < 0.3\ S$$

and for black soil regions with AMCII and AMCIII conditions

$$Q = \frac{(R - 0.1S)^2}{(R + 0.9S)},\ \text{if } R > 0.1S \qquad (16)$$

$$Q = 0,\ \text{if } R < 0.1\ S$$

However, in real situations, the AMC value is not restricted to the three discrete conditions identified empirically for the cumulative rainfall but can vary over a continuous range, and the value of S can be directly related to the soil moisture content in the active layer by the equations of Sharply and Williams (1990)

$$S = S1\ \{1 - FFC/[FFC + \exp(w1 - w2 \times FFC)]\} \qquad (17)$$

where S1 is the value of S associated with CN1 (S2 for CN2 and S3 for CN3), FFC is the fraction of field capacity (FC) and w1 and w2 are called shape parameters. The value of FFC is given by:

$$FFC = \frac{MC_1(t-1)}{K_1(t)} \qquad (18)$$

The shape parameters are defined as

$$w1 = \ln[1.0/(1.0 - S3/S1) - 1.0] + w2 \qquad (19)$$

$$w2 = 2\{\ln[0.5/(1.0 - S2/S1) - 0.5] - \ln[1.0/(1.0 - S3/S1) - 1.0]\} \qquad (20)$$

The average condition CN (CN2) was decided on the basis of hydrologic soil group and land use pattern. The CN1 and CN3 were calculated from Eq. (13) and (14) respectively. Corresponding S1, S2 and S3 values were calculated from Eq. 12 using CN1, CN2 and CN3 values. The shape parameters w1 and w2 were calculated using Eq. 19 and 20. The retention parameter S was calculated from Eq. 17 using the fraction of FC value (Eq.18) which depends on soil type and w1 and w2 values. Daily runoff was calculated using S and daily rainfall data from Eq. 15 as the soil of the region is alluvial.

Evapotranspiration models (ET)

In the present study, four ET models given by Thornthwaite and Mather (1955), Rijtema and Aboukhaled, 1975 (Doorenbos and Kassam, 1979), FAO (Frere and Popov, 1979) and Rijks, 1981 (Oldeman and Frere, 1982) were used to evaluate soil moisture content in the rootzone.

Thornthwaite and Mather (1955) established a linear relationship between actual ET (AET), potential ET (PET), soil moisture content in the rootzone (MC_1) and available water holding capacity (K_1) and is given as:

$$AET(t) = \frac{PET(t)MC_1(t)}{K_1(t)} \qquad (21)$$

Rijtema and Aboukhaled, 1975 (Doorenbos and Kassam, 1979) proposed that actual ET (ET) occurs at a maximum rate called potential ET (PET) as long as the soil moisture content in the root zone (MC_1) is more than a minimum threshold. When water content falls below the threshold value, the value of AET become a decreasing function of water content. The threshold value depends on the type of crop and PET and is given as:

$$ET(t) = PET(t), \quad \text{if } MC_1(t)\,^{3}\,(1-p)\,K_1(t) \qquad (22)$$

$$ET(t) = \frac{MC_1(t)}{(1-p)\,K_1(t)}, \quad \text{if } MC_1(t) < (1-p)\,K_1(t) \qquad (23)$$

where p is the soil water depletion factor. The value of p for different crops and rates of PET are listed by Doorenbos and Kassam (1979).

Frere and Popov (1979) of FAO proposed a water balance to calculate water requirement satisfaction index (WRSI) which indicates in percentage the extent to which water requirements of a crop are satisfied cumulatively throughout its growing cycle. According to them, actual

ET (AET) is equal to potential ET (PET) as long as the soil moisture content in the root zone (MC1) is greater than or equal to PET and the actual ET (AET) is equal to soil moisture content in the root zone (MC_1) when the actual soil moisture content in the rootzone (MC_1) is less than the PET and is given as:

$$AET(t) = PET(t); \quad \text{if } MC_1(t) \geqslant PET(t) \tag{24}$$

$$AET(t) = MC_1(t), \quad \text{if } MC_1(t) < PET(t) \tag{25}$$

Rijks, 1981 (Oldeman and Frere, 1982) established a simple exponential relationship between the actual soil moisture content in the root zone (MC_1), available water holding capacity (K_1), actual ET (AET) and potential ET (PET) and is given as:

$$AET(t) = PET(t)[1.03 - \exp(-3.5\ MC_1(t) / K_1(t))] \tag{26}$$

To obtain PET, the reference ET (ET0) is ultiplied by the corresponding value of the crop coefficient (K_C) for the day

$$PET(t) = K_C(t) \times ET0(t) \tag{27}$$

Reference ET (mm day^{-1}) was determined using the modified Penman method with locally obtained meteorological data by applying the procedures given by Doorenbos and Pruitt (1977). Solar radiation was calculated from sunshine hours using the Angstrom equation applied to the Delhi region (Gangopadhyaya *et al.*, 1970). Crop coefficients (K_C) were adopted from Jadav *et al.* (1997). The K_C for each value of DAS of crop was converted into value for each day by interpolation.

Computer programmes were written for the four water balance models in Fortran 77 language to simulate the root zone soil water content using the above mentioned criteria.

Field Experiment

The four soil water balance models were tested at the experimental farm of the Indian Agricultural Research Institute (IARI), New Delhi during 1997-98. The farm is situated at latitudes 28°37 to 28°39N and longitudes 77°9'E to 77°11'E and elevation range from 217 to 241 m above mean sea level. The climate of Delhi is subtropical semi arid with hot, dry summers and cool winters. The mean annual rainfall is 710 mm (average of past 30 years) of which as much as 75 percent is received during the monsoon months (July to September).

The soil of the experimental field belongs to the major group of Indo-Gangetic Alluvium (Type Ustochrept). The relief is nearly level with almost uniform slope ranging from 1 to 3%. The profile water balance models were tested by comparing with field observations of soil moisture made in the study area during 1997-98. Chickpea (gram) variety RS-10 was grown as rainfed with a row spacing of 30 cm. Soil moisture measured at weekly intervals from the beginning of crop growth until harvest was used to evaluate the model performance. Soil samples were collected with a soil auger at 15 cm depth

Table 1 : Soil properties of two soil series of Indian Agricultural Research Institute Farm

Soil Series	Texture	Bulk density (mg m^{-3})	Soil Water retention 0.033 MPa (mm cm^{-1})	Soil Water retention 1.5 MPa (mm cm^{-1})
Holambi	Loam	1.53	2.63	1.04
Jagat	Clay loam	1.56	3.64	1.64

Table 2 : Gram crop phenology and other data used in the models

Crop	DS	RDM	DTM	NDE	NDVP	NCP	NCG	FSM
		mm	Days					mm cm^{-1}
Gram (Holambi)	15 Dec.1997	1300	85	20	50	112	2	1.97
Gram (Jagat)	20 Dec.1997	1300	85	20	50	112	2	2.73

DS, date of sowing; RDM, maximum root depth; DTM days after sowing to reach RDM; NDE, number of days for establishment phase; NDVP, end day of vegetative phase; NCP, length of crop period; NCG, number of the crop group for soil water depletion factor (Doorenbos and Kassam, 1979); FSM, soil moisture content at the end of the day of sowing.

intervals down to 105 cm. For each soil series, four locations were sampled within a block of agricultural field for each moisture content observation. The size of each block varied between 1 and 2 ha.

The values of AET and soil moisture content in the root zone at the end of each day were modelled for the entire growing season (December to April) of 1997-98. The predicted values of daily soil moisture content in the root zone were compared with the observed field moisture data. In the beginning of the crop growth, observed soil water data were considered upto the root depth calculated by the empirical root growth model. When the root growth was more than 105 cm, the observed values were considered upto 105 cm depth.

The data used to run the models were daily weather data of rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hours recorded in the observatory of Division of Agricultural Physics at IARI, New Delhi from November to April 1997-1998.

Soil properties of different soil series and crop information were adapted from Mandal *et al.*(2002) and those are given in Tables 1 and 2 respectively.

Testing the performance of the models

For testing of these models, coefficient of determination (r^2) and standard error were calculated using observed values (O) and predicted model values (P) of soil water content. Willmott (1982) recognized that

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Table 3 : Percent deviation of soil water content at different depths during the growth period of gram in Holambi soil series

DAS	Soil depth (cm)	Deviation of soil water content (%)			
		Thornthwaite & Mather	Rijtema & Aboukhaled	Rijks	FAO
3	15	1.55	3.61	3.09	3.61
8	15	-4.57	2.29	0.57	2.29
14	15	-14.56	1.32	-3.97	1.99
19	18	-8.93	6.05	0.86	6.05
25	29	-8.61	7.42	1.48	7.42
32	43	-9.88	7.41	0.62	7.41
37	55	-22.32	-2.97	-9.88	-2.28
43	69	-18.83	0.07	-7.36	0.74
51	87	-7.47	8.60	2.87	11.49
58	101	-10.77	7.17	0.99	11.50
66	115	-14.80	4.76	-1.76	10.63
75	125	-10.84	8.25	1.47	15.02
84	129	-10.59	7.83	1.50	15.32
92	130	-19.18	0.18	-6.47	9.86
99	130	-22.78	-0.63	-8.86	8.86
106	130	-25.16	-0.39	-9.24	9.39

the magnitudes of r and r^2 are not consistently related to the accuracy of prediction. So, he proposed using an Index of agreement -D along with several other statistical measures to evaluate model performance. The value of D is calculated as follows:

$$D = 1 - [\, \Sigma (P_i - O_i)^2 / \Sigma(|P_i - O| + |O_i - O|)^2] \qquad (28)$$

where O = mean of observed soil water content values.

The D-index is more sensitive to systematic model error than are r and r^2 and reflects systematic model bias when coupled with r^2 statistic. Value of D range from 0.0 for complete disagreement to 1.0 for perfect agreement. Other measures of model performance included in this paper are the systematic (E_s) and unsystematic (random) (E_u) components of the root mean square error (RMSE) and the mean absolute error (MAE) - a measure of the average magnitude of the differences between the predicted and actual values which is considered to be less sensitive to extreme values, than is RMSE (Fox, 1981). Systematic error is related to the model performance and random error is related to observations or measurements.

Table 4 : Percent deviation of soil water content at different depths during the growth period of gram in Jagat soil series

DAS	Soil depth (cm)	Devidation of soil water contain (%)			
		Thornth waite & Mather	Rijtema & Aboukhaled	Rijks	FAO
3	15	0.74	2.97	2.23	2.97
9	15	-5.42	0.41	-1.21	0.41
14	15	-7.91	1.98	-1.19	1.98
20	20	-12.93	-0.43	-4.74	0.00
27	33	-9.40	3.85	-1.28	3.85
32	43	-8.12	4.70	0.00	5.13
38	57	-8.58	4.29	-0.86	4.72
46	75	-6.37	4.78	0.40	7.17
53	91	-7.02	6.20	1.23	8.68
61	107	-9.09	4.31	-0.86	8.19
70	120	-9.32	4.66	0.00	9.32
79	128	-7.14	5.75	1.98	11.90
87	130	-12.30	2.88	-2.88	8.23
94	130	-13.90	-2.95	-3.38	8.44
101	130	-18.67	0.44	-7.11	6.22
108	130	-14.16	4.72	-2.58	10.73

$$E_s = [N^{-1}\Sigma(P_{ri} - O_i)^2]^{1/2} \qquad (29)$$

$$E_u = [N^{-1}\Sigma(P_i - P_{ri})^2]^{1/2} \qquad (30)$$

$$RMSE = (E^2_s + E^2_u)^{1/2} \qquad (31)$$

$$MAE = (N^{-1}\Sigma|P_i - O_i|) \qquad (32)$$

where, P_{ri} is calculated from the slope, b and an intercept a of the regression of predicted on observed soil water content values (such that $P_{ri} = a + bO_i$); N is the number of observations.

RESULTS AND DISCUSSION

The soil moisture content in the initial stages of crop growth was high and decreased gradually as the crop reached maturity. Like observed values, the simulated values of soil moisture in Jagat soil series were more than in the Holambi soil series. Soil water balance models of Rijks and Rijtema and Aboukhaled predicted the actual soil water content more or less closely throughout the crop-growing season in both the soil series. Whereas Thornthwaite and Mather model gave over estimates and FAO model predicted under estimated values in both the soil series (Fig. 1 and Fig. 2). This is attributable to the different methods employed in estimating actual ET by these water balance

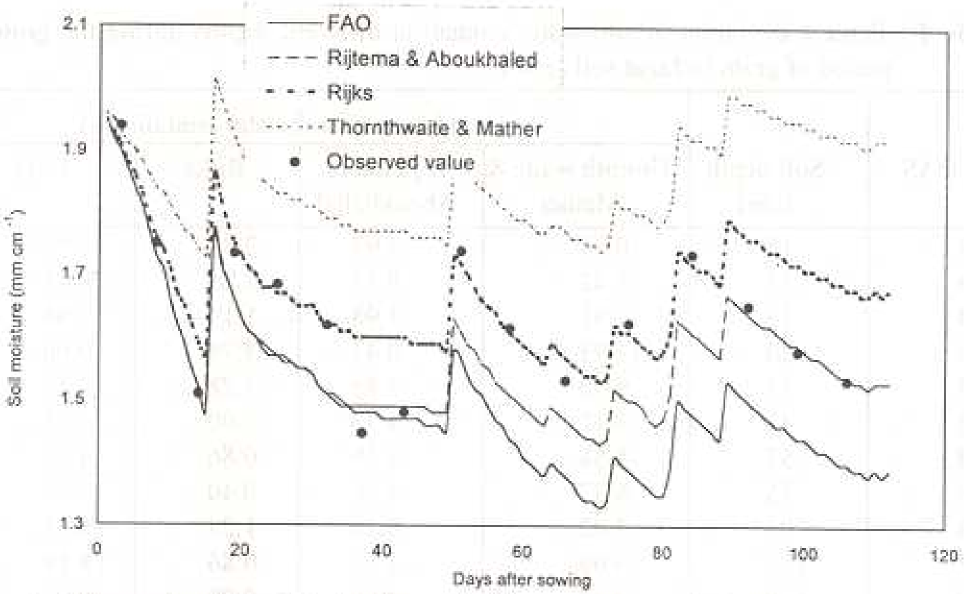

Fig. 1 : Observed and predicted values of soil water content during the growth period of gram in the Holambi soil series

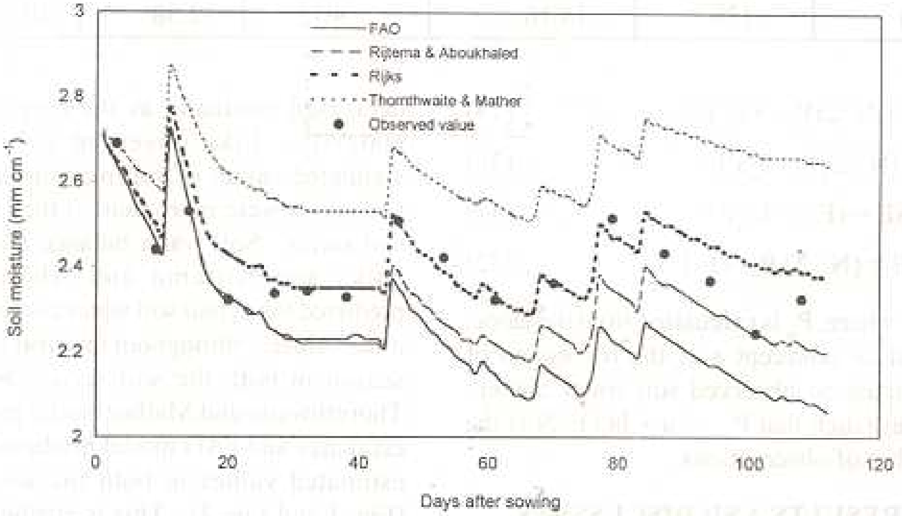

Fig. 2 : Observed and predicted values of soil water content during the growth period of gram in the Jagat soil series

Table 5 : Statistics for testing the performance of water balance models in Holambi and Jagat soil series

Soil series	Water balance model	r^2	D-index	E_s	E_u (mm cm^{-1})	RMSE	MAE
Holambi	Thornthwaite & Mather	0.27	0.48	0.222	0.063	0.231	0.024
	Rijtema and Aboukhaled	0.75 **	0.85	0.072	0.053	0.090	0.0004
	Rijks	0.67 **	0.85	0.063	0.048	0.079	0.009
	FAO	0.62 *	0.72	0.125	0.077	0.147	0.009
Jagat	Thornthwaite & Mather	0.21	0.45	0.235	0.061	0.243	0.021
	Rijtema and Aboukhaled	0.81 **	0.83	0.086	0.048	0.098	0.007
	Rijks	0.74 **	0.89	0.048	0.042	0.063	0.004
	FAO	0.64 **	0.67	0.147	0.083	0.169	0.016

** Statistically significant at $P< 0.01$

* Statistically significant at $P< 0.05$

r^2 : Coefficient of determination; D-index: Index of agreement Es: Systematic error;

E_u: Un systematic error; RMSE: Root mean square error; MAE: Mean absolute error.

models.

The percent deviation of soil water content at different depths from observed soil water content in Holambi and Jagat soil series (Tables 3 and 4) show that Rijks model slightly over predicted the soil moisture content in both the soil series. In Holambi soil series, the deviation was -7 to -10% at 37-43 DAS and -6 to -9% at 92 DAS and onwards. In Jagat soil series, the deviation was well within ± 5% throughout the growing season except at 101 DAS (-7%). Where as, Rijtema and Aboukhaled model gave slightly under estimates in both the soil series. The deviations were slightly less in Jagat soil series than in Holambi soil series. Over all, deviations ranged from 2 to 8%. Deviations in the case of Thornthwaite and Mather model ranged from -5 to -25% in Holambi soil series and -5% to -19% in Jagat soil series. In the case of FAO model, the deviations ranged from 2 to 15% in Holambi soil series and 0.4 to 12% in Jagat soil series.

Statistics for testing the performance of these four soil water balance models in both the soil series were given in Table 5. In Holambi soil series both r^2 (0.27) and D-index (0.48) values for Thornthwaite and Mather model were the lowest. Even error values were high. The values for E_s and E_u were 0.222 and 0.063 mm cm^{-1} respectively resulting in high RMSE (0.231 mm cm^{-1}). The MAE (0.024 mm cm^{-1}) value was also high for this model. The high degree of systematic error was evident in Fig. 1 as all the simulated values were over estimated. The values of r^2 (0.62) and D-index (0.72) for FAO model were higher than Thornthwaite and Mather model but less than Rijks and Rijtema and Aboukhaled models. The error values E_s and E_u were also relatively higher (0.125 and 0.077 mm cm^{-1}, respectively) which resulted in high RMSE (0.147 mm cm^{-1}). This was clearly seen in Fig 1. as all the simulated values were under estimated, even though r^2 and D-index values were high. Rijks and Rijtema and Aboukhaled models perform relatively better as both r^2 (0.67 to 0.75) and D-index (0.85) values were high which indicate close agreement between observed and predicted values. The E_s (0.062 - 0.063 mm cm^{-1}) and E_u (0.048 - 0.053 mm cm^{-1}) values and RMSE (0.079 - 0.090 mm cm^{-1}) and MAE (0.0004 - 0.009 mm cm^{-1}) values were also small for these models. Similar observations were noticed for Jagat soil series also (Table 5).

CONCLUSIONS

Based on the statistical results, it would appear that both Rijks and Rijtema and Aboukhaled models are comparable and can be used to simulate root zone soil moisture content since over all deviations are well with in ± 10%. Thornthwaite and Mather model and FAO model do not appear suitable for estimating root zone soil moisture content under the test conditions.

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