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Soil Moisture Contents as a Determining Factor Machinery Selection

1. Development of computerized simulation model for the prediction of daily fluctuations in soil moisture content

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ABSTRACT

A simulation model to predict the daily fluctuations of soil moisture content was developed using the Versatile Soil Moisture Budget (VSMB) equation by employing pascal computer language. The model was tested against actual field data and showed fairly accurate results. The correlation coefficient 0.99 .

INTRODUCTION

The major problem in all semi-arid regions is the short time available for tillage. This is due to the fact that under arid conditions the seeds should be sown as soon as possible after the rainy season begins to attain the full benefits of the vegetation period; and any delay shortens the growth period of the crop, because ripening begins anyhow with the onset of the dry season, resulting in yield losses and lower crop qualities. Soil tillage cannot, however, begin until the rainy season starts, and if tillage is carried out too early, the soil surface may slake, reducing the infiltration of rain water and causing surface runoff (Krause and Lorenz, 1984).

Clay soils, under rainfed agriculture, can be worked with a relatively low input of energy only during a short period after the first rains because the water content of the topsoil changes very rapidly. When the clay soil is too dry it may become rock hard, and when too wet it may not be workable (Allman and Knoke, 1947).

Another problem is that the crop yield under arid conditions is highly dependent on rainfall. Below average rainfall may result in complete crop failure, which causes complete loss of the inputs of soil tillage, seeds and labour, and leaves the bare soil virtually without protection against the wind and sun, thus making it extremely susceptible to erosion.

A third problem is that productivity in arid regions is decreasing annually because of the decreasing amount of rainfall, extensive rotations as well as financial constraints.

Any attempt to estimate the quantity and availability of soil moisture content must be based on a thorough understanding of the dynamic balance of water in the soil. The soil water balance (Δ W) is the difference between the amount of water added (Wa) and the amount of water withdrawn (W w) during a certain period of tinie as given by following equation (Simalenga, 1989):

$\Delta W = Wa - Ww$ ………………………………………(1)

Rain or irrigation water constitutes the main source of water added to the soil. Part of this water will be lost as surfae runoff depending on the land slope, grass cover, soil type and rain intensity; part will evaporate directly from the soil surface; some is taken up by plants for growth some may percolate deep into the soil beyond the root zone; whereas remainder adds to the moisture storage at the root zone (Hillel, 1980).

Several models for estimating soil moisture, utilizing hydrological data, have been reported (Shaw, 1963; Ligon *et al*., 1965; Nath and Johnson, 1980).

Witney and Oskoui (1982) modified and simplified the soil moisture balance equation to the following form:

$M = Mp + pr - R\ Pe - ET$……………………(2)

Where:

M = Soil moisture content (mm).

Mp = Soil moisture content on previous day (mm)

Pr = Precipitation (mm).

R = Runoff (mm).
Pe = Percolation (mm).
ET = Evapotranspiration (mm).

In order to apply Equation (2), its components can be determined as follows:

a) Evapotranspiration (E T)

Direct measurement of evaptranspiration can be made by lysimeter Schwab *et al*, 1966), but it is expensive. On the other hand, Fadl (1978) used the neutron probe for the daily measurement of soil moisture and it showed an erratic pattern of ET which is also expensive and dangerous. Moreover, Farbrother (1969) published relative turgidity curves to estimate ET from irrigated cotton fields in the Gezira Research Station. Many recent studies have advocated using the Penman-Monteith equation for estimating ET (Doorenbos and Bruitt, 1975). The equation states that:

$$\mathrm{PET}=\{\Delta/\Delta+\gamma)\ (Rn-G)+\{Y/\Delta+Y\}\ (15.36)\ (1+0.0062S_2)\ (e_s-e_{a)}..(3)$$

Where:
PET = Potential evaptranspiration (cal-cm^{-2} –day).
Δ= Slope of saturation vapor pressure (mb-°C).
γ = Radiation reflection coefficient (0.05 for water Surfaces and 0.2 for green crops).
Rn = Net radiant energy available at the surface (calcm^{-2}-day^{-l}).
G = Energy into the soil (cal-cm^{-2}-day^{-l}).
S_2 = Average wind velocity at mean dewpoint temp.
(Mb-0C).
^{e}s = Mean saturated vapor pressure (mb).
^{e}d = Saturated vapor pressure at mean dewpoint temp. (mb-^{0}C).

McCulloh (1965) modified the Penman-Monteith equation so as to incomorate the effect of altitude, and the Penman tables have been recalculated from the following equation:

$$\mathrm{PET}=\{\Delta/\Delta+\gamma\}\{Ra-(1-r)(0.02\ \mathrm{Cos}\emptyset+0.52n/N\}\{\Delta/\Delta+\gamma\}$$
$$\{\sigma\ Ta^4=(0.10-0.9n/N)(0.56-0.08ed^{0.5})\}+\{\gamma/\Delta+\gamma\}$$
$$\{0.26(1+h/20000)(1+u/100)(e_s-e_d)\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

where:

Ra=Radiation of the outer limit of the earth atmosphere(cal-cm^{-2}day-^{1}).

γ=Radiation reflection coefficient (0.05 for water surfaces and 0.2 for green crops).

n/N = Ratio of actual. to possible hours of sunshine.

$\sigma =$ Stefan-Boltzman constant (11.7 x 10^{-8} cm/day).

H = Altitude (m).

U =.Daily wind run at a height of 2m (km/day).

$\phi =$ Latitude.

Ta = Ambient air temperate (K = C+273).

French studies (Gosse et al., 1977; Katerj and Perrier, 1983) have used the Penman-Monteith equation and advocated its use throughout France for direct computation of crop evapotranspiration.

Actual evapotranspiration (AET) can be obtained by applying some correction factors to the potential evapotranspiration, such as soil factor surface cover factor and rainfall distribution factor (Simalenga, 1989) as follows:

AET = (PET)(kd)(ks)(kr)………………(5)

Where:

AET= Actual evapotranspiration

kd = Soil dryness factor

ks = Surface cover factor

kr = Rain distribution factor

Adam and Farbrother (1977) found that for bare soil the soil dryness factor (kd) is 0.55.

The soil surfaces cover factor can be determined by the following equation (Gerb, 1996):

ks = 1-0.005PSC…………………..(6)

Where :

PSC = Percent soil cover.

The rainfall distribution factor (kr) was developed by Schwab *et al.* (1966*)* as shown in Table (l).

Table l. Rainfall correction factor (Schwab *et al*., 1966).

Number of consecutive days without rain	Kr
0	I .00
2-1	0.75
5-3	0.65
5-above	0.55

(b) Runoff (R)

Runoff is that portion of the precipitation that makes its way toward streams, lakes, channels or oceans. The runoff volume is affected by rainfall intensity and the watershed characteristics such as size, slope, orientation or topography, geology and surface cover. There are different methods for estimating runoff volume, but USDA-SCS equation and the runoff number techniques were considered to be most accurate (Hudson, (1975). The equation developed in this regard states that:

$Q= (Ra-0.2S)^{2/}(Ra+0.85)$……………………..(7)

Where:

Q = Direct runoff (mm).

Ra = Rainfall (mm.(

S = Maximum potential difference between rainfall and
runoff (Watershed storage parameter, mm).

In this equation (S) is determined as a function of the runoff curve number (RCN) such that:

$S=\left(25400/RCN\right)-254$…………………………………………..(8)

RCN varies between 0 and 100 depending on the soil type, infiltration properties, vegetation cover, antecedent moisture content and land use practices; and it can be determined from Table (2).

Table 2. Determination of RCN (Schwab *et al.*, 1966).

Land user or cover	Treatment or Practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow row crop	Straight row	-	77	86	91	94
Row crop	" "	Poor	72	81	88	91
	" "	Good	67	78	85	89
	Non contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	good	62	71	78	81
Small grains	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
	Terraced	Good	59	70	78	81
Close seeded	Straight row	Poor	66	77	85	89
Legume or	Straight row	Good	58	73	81	85
Rotation meadow	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Terraced	Poor	63	73	80	83
	Terraced	Good	51	67	76	80
Pasture or range	"	Poor	68	79	86	89
	"	Fair	49	69	79	84
	"	Good	39	61	74	80
	Contoured	Poor	47	67	81	88

(c) Percolation (Pe)

Percolation refers to the entry of water into the soil. It is the source of soil moisture to sustain the growth of vegetation and the ground water supply of wells, springs and streams (Schwab *et al.*, 1966). Percolation affected by the soil type, vegetation cover, land slope as well antecedent moisture content.

Hunt (1986) indicated that the amount of free water percolated per day is inversely proportional to the wilting point and directly proportional to the moisture above field capacity.

A more simplified method for estimating percolation was developed by Hunt (1986), as follows:

D = Free water above field capacity/2PWP…….. (10)

Where.

PWP = Permanent wilting point (mm).

The objective of this research is to develop a computer model to Estimate the soil moisture content at the top 300 mm of the soil.

MODEL DEVELOPMENT

In order to develop a computer model to predict the daily fluctuation of soil moisture content, the water balance equation (I) was used. The components of the equation were modeled using Pascal language, and the input data were as follows:

(l) Soil physical properties (FC,PWP, and soil type), initial moisture content and some correction factors (kr, ks and DC).

(2) Record of the daily rainfall and potential evapotranspiration.

The general features of the model were as depicted in Fig. l, and can be summarized as follows.

(l) The model works in English and uses SI units

(2) RI-he basic structure of the model is fairly typical, since there is a menu to allow the user to enter the initial data.

(3) Input data entry is made directly to the screen.

(4) Output data will be displayed on the screen and they include the AET, runoff, percolation and moisture content.

Initially, evapotranspiration is obtained by entering the meteorological data which are radiation, hours of sunshine, wind velocity, saturation vapor pressure and energy in the soil.

The operational steps of the soil moisture prediction model were as follows:

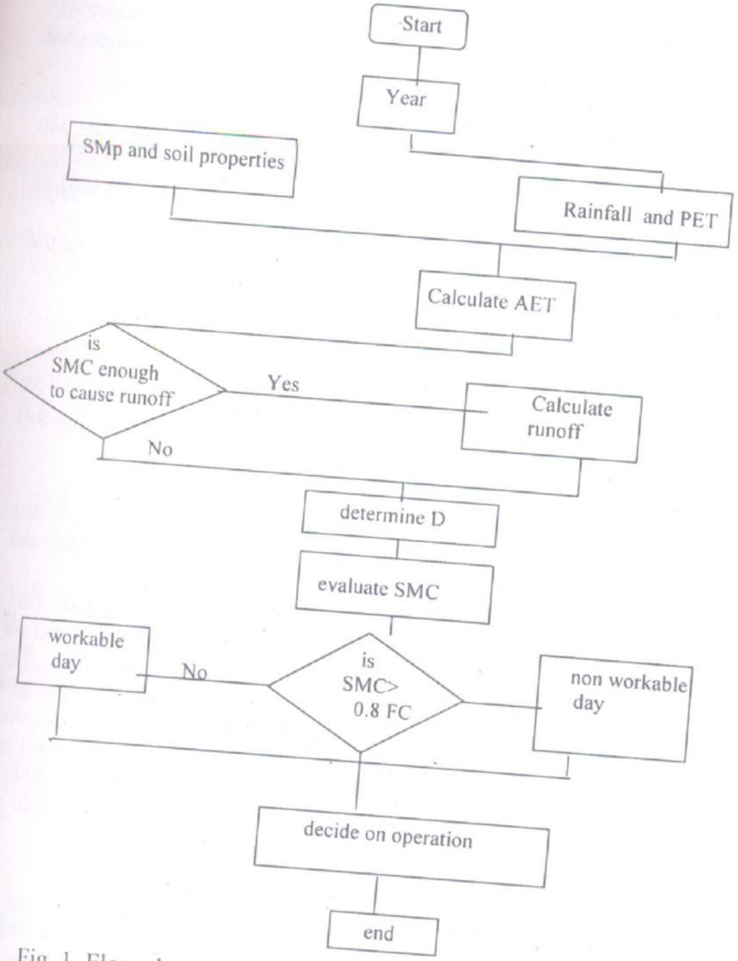

Fig. 1. Flow chart for soil moisture and trafficability prediction model

Step I:

This involves entering the SMp, soil physical properties (FC,PWP), PET, rainfall and correction factors and constants. Then the model will calculate the AET according to equation (5). The correction factors used were kd = 0.55,ks=1 and kr=0.55 according to Table 1.

Step II:

If the amount of rainfall is enough to cause runoff, then the in model will calculate the runoff from equation 7.

RCN was determined from estimates of the Schwab *et al*. (1966) as shown in Table 2.

The model will determine the value of the maximum potential difference between rainfall and runoff as follows:

$S = (25400/89)-254 = 31.39$

step III:

The model, then calculates percolation according to equation 10

step IV:

From SMp, AET, Ra, D and runoff the model will calculate the soil moisture content of a specified day.

MODEL VERIFICATION

In order to verify the ability of the model to predict the SMC, it was tested against the moisture depletion curve developed by Adam and Farbrother (1977) for irrigated clay soils.

By assuming a field fully saturated with water (140mm), daily PET (from Wad Medani Meteorological Station) was entered in the model for 18 rainless days. The model evaluated the SMC on daily basis. The results were plotted against the moisture depletion curve of Adam and Farbrother (1977). The comparison between the predicted and measured values of SMC (Table 3) showed very close agreement. The result of correlation analysis between the predicted and measured data gave a correlation coefficient of 0.99. This proved that the model was able to predict the soil moisture content with a high degree of accuracy.

Application and limitations of the model

It has been shown that the water balance equation can be used to estimate SMC. To change the model to estimate SMC at another location with different soil type, different parameters will have to be calculated before use in the model for the new location and soil characteristics.

Actual field tests have to be conducted to see if the assumptions made during the model development are valid for another locational with similar soil type before using the model

Table 3. Measured and predicted SMC

Days after saturation	Measured SMC (mm)	Predicted SMC (mm)
2		
4	132.0	105
6	104.0	85
8	80.6	75
10	64.0	63
12	50.6	45
14	42.2	35
16	38.8	30
18	25.2	29
20	19.5	28

CONCLUSIONS

From the results of this research work, the following conclusions can be drawn:

(l) It was possible to develop a computer model to evaluate daily changes of soil moisture content.

(2) Assumptions regarding the use of the developed model, concerning soil dryness. surface cover and rainfall distribution factors proved to be valid for the case under study.

(3) Using the Versatile Moisture Budget equation, the daily changes of SM can be predicted fairly accurately from the model using the soil characteristics and weather data.

(4) The model as tested against actual field data and proved to be fairly a curate.

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