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Development of a Simple Parametric Model to Estimate Soil Water Evaporation in Relation to Soil Texture, Evaporativity, Tillage and Crop Residue Management

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ABSTRACT

Laboratory experiments were conducted to assess the soil water evaporation parameters in relation to soil texture, evaporativity, tillage and crop residue management. Using these parameters, a simple model was developed. The cumulative evaporation trends estimated with the model and observed experimentally under varying soil and weather conditions by other researchers matched well.

Introduction

Water loss by evaporation from soil is known to occur in three distinct stages viz. constant-rate stage, falling-rate stage and low-rate stage. The evaporation rate during the constant-rate stage is limited by evaporativity dictated by solar radiation, temperature and wind speed and soil albedo, that in falling-rate stage by soil water transmission properties (diffusivity-water content relations), and in low-rate stage by molecular diffusion of vapours. A major portion of the total water loss by evaporation occurs in the first two stages. Tillage and crop residues are commonly used for reducing the evaporation losses. Jalota and Prihar (1998) reported that these practices alter the time trends of evaporation from treated vis-à-vis untreated soil depending upon the soil type, evaporativity, tillage variables (time and type of tillage, depth of tillage and characteristics of the tilled layer) and crop residue management (amount, type and manner of placement).

In water balance and hydrological studies evaporation from soil is estimated by different models varying from simple parametric to mechanistic. The parametric models are used in general because of their modest input requirements. Inspite of their simplicity, their use remained limited for want of the evaporation parameter needed for a given soil and climatic conditions. In fact, the information on evaporation parameter as influenced by soil type, evaporativity, tillage and crop residue management is limited. Therefore, to make the parametric model more useful for diverse situations the present study was undertaken with the following objectives:

1. to estimate evaporation parameters for a range of evaporativity, soil type, tillage and crop residue management practices.
2. to develop relations between evaporation parameter and variables affecting it.
3. to validate the relations on independent experiments.

Materials and Methods

Laboratory experiments were conducted under controlled conditions. Columns 95 cm long x 10 cm diameter of PVC fitted with perforated metallic lids at the bottom and 5 cm detachable collars at the top were filled to bulk densities of 1.42 Mg m^{-3}, 1.52 Mg m^{-3} and 1.60 Mg m^{-3} with silt loam (53% sand, 29% silt and 18% clay), sandy loam (71% sand, 11% silt and 18% clay) and loamy sand (86% sand, 6% silt and 8% clay) soils, respectively. Columns were wetted from the top with sufficient water to bring them to field capacity water contents of 0.30, 0.23 and 0.14 m^3 m^{-3} for silt loam, sandy loam and loamy sand, respectively. The applied water was allowed to redistribute for 2 days without evaporation. The collars were removed from the columns and soil was cut flush with the upper rim of the column. The columns were allowed to dry in a wooden chamber (180 cm tall, 70 cm wide and 145 cm long) in which humidity, temperature and wind speed were controlled to achieve different potential evaporation rates-Eos (Jalota and Prihar, 1992). Evaporation was computed as the loss in weight of columns to an accuracy of ± 0.013 cm. Treatments of tillage (2cm and 5 cm deep) and of wheat-straw mixing (3 Mg ha^{-1} and 6 Mg ha^{-1} mixed in 0-5 cm surface soil) were imposed as and when the soil surface conditions became workable. The columns were placed at random in the chamber and allowed to dry under a given E0. Evaporation losses were measured up to varying period ranging 38-54 days depending upon the evaporativity. The location of the columns was changed at each weighing.

From the observed data on cumulative evaporation from the commencement of evaporation, evaporation parameters ß and K as reported by Boesten and Stroosnijder (1986) and Jalota et al. (1988) were estimated by regressing CE with $t^{0.5}$ and $CE_0^{0.5}$, respectively for untreated and treated as tillage and residue-mixed soil conditions. From the estimated evaporation parameters ß a relationship of the type [a $(MWD)^b$ E_0^c) between mean weighed diffusivity (MWD) of the soil and E_0 was developed. The MWD was calculated using the following relation:

$$D = \frac{1.85}{(\theta_i-\theta_a)^{1.85}} \int_{\theta_a}^{\theta_i} D(\theta)\,(\theta-\theta a)^{0.85}\, d\theta$$

The effects of tillage depth and rate of residue-mixed on the ß were also quantified from the observed data. The developed relations were validated by comparing the estimated evaporation (from these relations) and the observed data set of independent experiments.

Results and Discussion

Evaporation parameters

In untreated soil ß decreased with E_0 in sandy loam and loamy sand soils and was little affected in silt loam. The values of coefficient of variation (CV) were 1.9%, 14.9% and 16.8%, for silt loam, sandy loam and loamy sand, respectively (Table 1). More than 10% CV values in untreated sandy loam and loamy sand, tilled or residue- mixed silt loam soil indicated the assumption made by Boesten and Stroosnijder (1986), CE_0 integrates the effects of time and E_0 and the ß value determined for one set of evaporativity can be used for the other evaporativity, may not hold true in the above said soil conditions. With tillage the ß values decreased in all soils and evaporativities except in silt loam soil under an E_0 of 0.4 cm day^{-1}. However, the decrease in ß value was more with deeper tillage. This indicates that in finer textured soils under low E_0 evaporation can be more with tillage because of the re-establishment of the capillaries, which provide upward liquid flow for a long period (Jalota and Prihar, 1992). This trend is in line with the results of Jalota and Prihar (1990) showing an interaction between soil type and evaporativity. Residue-mixing treatment has also decreased the ß values with the magnitude greater than that with tillage alone. The decrease was more with higher rate of residue.

The value of evaporation parameter, K, increased with evaporativity in untreated, tilled and residue-mixed treatments in all the three soils. However, the increase was up to 1.01 cm day^{-1} evaporativity and decreased under evaporativity higher than this. This shows that CE under E_0 of 1.01 cm day^{-1} can exceed that under E_0 of 1.30 cm day^{-1} in sandy loam and loamy sand soils. These results corroborate the findings of Jalota and Prihar (1986) which indicated that CE under lower E_0 exceeds than that under higher E_0 in soils which replenish water supply from lower layers to the surface layers at slower rate because of the sharper decrease in water transmission parameter, D(θ) or K(θ), with decrease in soil water content and higher E_0.

Developed relations

Mwendra and Feyen (1997) reported that model based on easily measurable parameter (such as E_0) rather than on time is more useful under field conditions where drying cycles are often interrupted by rain and evaporativity is also fluctuating. To diversify the use of CE_0 based evaporation parameter ß for different soil textures and evaporativities, ß was related with mean weighted diffusivity (MWD) of the soil and E_0. The relation developed was

$$ß = 0.079\ (MWD)^{1.052}\ (E_0)^{-0.157} \quad r^2 = 0.948 \qquad \text{.....(1)}$$

Where ß is in cm $cm^{-0.5}$, MWD is in cm^2 day^{-1} and E_0 is in cm day^{-1}.

The relationships between evaporation parameter and tillage depth (TD) and rate of residue-mixed (RR) in 0-5 cm surface soil for the three soils were also developed which are given below,

Silt loam soil

$$ß_t = ß(1-0.166\ (TD)^{0.5}) \quad r^2 = 0.948 \qquad \text{...(2a)}$$

$$ß_m = ß(1-0.300\ (RR)^{0.5}) \quad r^2 = 0.945 \qquad \text{...(2b)}$$

Sandy loam

$$ß_t = ß(1-0.283\ (TD)^{0.5}) \quad r^2 = 0.911 \qquad \text{...(3a)}$$

$$ß_m = ß(1-0.283\ (RR)^{0.5}) \quad r^2 = 0.926 \qquad \text{...(3b)}$$

Loamy sand

$$ß_m = ß(1-0.184\ (RR)^{0.5}) \quad r^2 = 0.920 \qquad \text{...(4)}$$

Table 1. Evaporation parameter ß and K for untreated (UT), tilled (T) to 2 cm and 5 cm deep, and rates of (3 and 6) Mg ha^{-1}) crop residue -mixed (RR) soils of varying texture

E_0 cmd^{-1}	ß $cm\,cm^{-0.5}$					K $cm\,t^{-0.5}$				
	UT	T		RR		UT	T		RR	
		2	5	3	6		2	5	3	6
Silt loam										
0.25	1.88	---	---	0.68	0.60	0.94	---	----	0.36	0.28
0.40	1.88	1.91	1.76	0.60	0.58	1.11	0.52	0.58	0.38	0.36
1.01	1.80	1.13	0.96	0.59	0.54	1.13	0.94	0.75	0.55	0.50
1.30	1.89	0.99	0.84	0.77	0.55	2.26	1.03	0.87	0.93	0.63
CV%	1.90	30.1	34.3	11.4	5.7	38.7	26.4	16.1	48.1	29.9
Sandy loam										
0.25	2.13	---	---	0.71	0.51	1.06	---	---	0.28	0.23
0.40	1.97	0.80	0.77	0.67	0.60	1.32	0.43	0.33	0.42	0.38
1.01	1.76	0.83	0.59	0.77	0.54	1.76	0.77	0.49	0.76	0.54
1.30	1.40	0.69	0.64	0.77	0.66	1.57	0.81	0.65	0.88	0.82
CV%	14.9	7.6	11.2	6.0	9.4	18.4	25.6	27.4	41.8	44.7
Loamy sand										
0.25	0.62	---	---	0.43	0.30	0.41	----	---	0.22	0.15
0.40	0.54	---	---	0.41	0.31	0.38	---	---	0.26	0.20
1.01	0.48	---	---	0.37	0.28	0.50	---	---	0.36	0.28
1.30	0.40	---	---	0.41	0.34	0.36	---	---	0.46	0.49
CV%	16.8	---	---	5.8	6.1	12.9	---	---	29.6	46.2

where $ß_t$ and $ß_m$ are evaporation parameters in $cm\,cm^{-0.5}$ for tilled and residue-mixed soil. TD is in cm and RR is in Mg ha^{-1}

Validation

The validity of the developed relations was tested on data sets of independent experiment for untreated and residue-mixed treatments, and that of published by Gill and Jalota (1996) for tilled soil. Evaporativity in the independent experiment was 0.50 cm day^{-1} and that in the published data was 0.87 cm day^{-1}. In both the experiments soil was sandy loam with MWD of 17.5cm^2 day^{-1}. Putting the value of MWD and E_0 in equation 1, values of ß for untreated soil was estimated, which resulted into 1.767 cm $cm^{-0.5}$. Evaporation parameter $ß_t$ and $ß_m$ for tilled and residue-mixed treatments, with equations 2b and 3b, resulted into 0.767 and 0.602 cm $cm^{-0.5}$, respectively. Another data set used for validation was by Prihar et al (1996) in which soil was loamy sand (MWD = 6.2 cm^2 day^{-1}) and Eo was 0.25 cm day^{-1}. ß Values estimated were 0.675 and 0.372 cm $cm^{-0.5}$ for untreated and wheat-straw (6 Mg ha^{-1}) mixed in 0-5 cm surface soil layer. Using these ß values cumulative evaporation (CE) was predicted with the modified Pan-E based functional model of Jalota (1998, unpublished), which is:

$$CE_1 = CE_0 \qquad CE0 < ß^2/4 \qquad ...(5a)$$

$$CE = ß\,(CE_0)^{0.5} - ß^2/4 \qquad CE0 > ß^2/4 \qquad ...(5b)$$

The predicted CE, with respective ß value obtained from the developed relations and using equations 5a and 5b, and observed CE matched closely (±0.5cm) in untreated, tilled and residue-mixed treatments for sandy loam and loamy sand soils (Figure 1). This indicated that developed relations are reasonably valid in diverse situations. Therefore, these can be used to simulate the direct and interactive effects of soil type, evaporativity, tillage and residue mixing on evaporation from soil.

Estimated evaporation trends

Trends of evaporation from two soils (MWD 25.0 and 5.0 cm^2 day^{-1} under three E_0,s (0.25,1.0 and 1.5 cm day^{-1}) were estimated

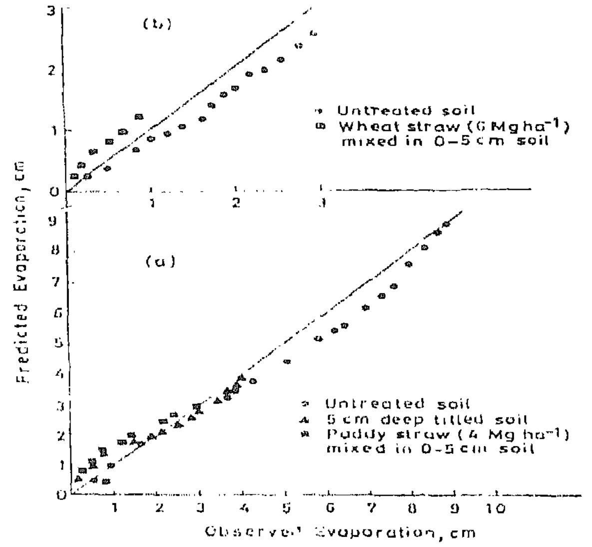

Fig. 1. Comparison of observed and predicted evaporation from untreated, tilled and residue mixed treatments in sandy loam (a) and loamy sand(b) soils.

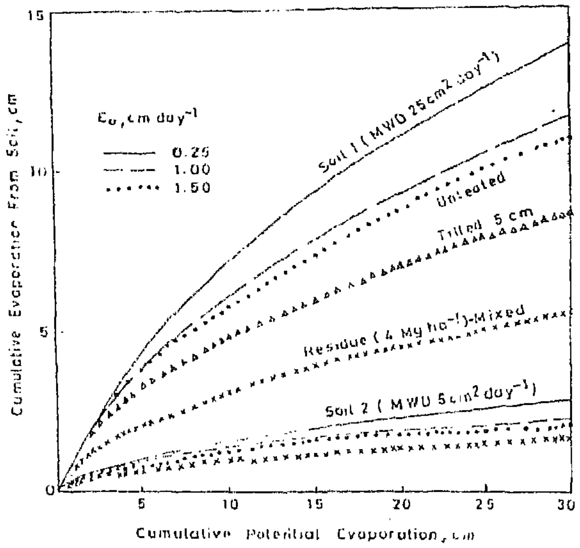

Fig. 2. Estimated cumulative evaporation as a function of cumulative potential evaporation as affected by soil type, evaporativity, tillage and residue- mixing

using the developed relations. Total evaporation estimated during the constant-rate stage was 2.1, 1.4 and 1.2 cm in soil 1,and 0.7, 0.5 and 0.4 cm in soil 2 under E_0's of 0.25, 1.00 and 1.50 cm day^{-1}, respectively. At the end CE was 13.8, 11.4 and 10.8 cm in soil 1, and 2.8, 2.3 and 2.1 cm in soil 2 under E_0's of 0.25, 1.0 and 1.5 cm day^{-1}, receptively (Fig. 2). Under an E_0 of 1.5 cm day^{-1}, estimated CE at the end was reduced to 8.6 cm with 5 cm deep tillage in soil 1. With residue (4 Mg ha^{-1}) mixed in 0-5 cm surface soil reduced CE to 5.6 cm in soil 1 and 1.7 cm in soil 2.

. As expected these results showed that CE during constant-rate stage decreased with increase in E_0 and is less in coarse textured soil having lower MWD. CE at a given CE_0 was less in soils with lower MWD. CE was more under lower E_0 compared to that under higher. CE was lesser with residue mixing and was intermediate with tillage alone. Residue mixed treatment decreased evaporation to a greater extent in soils with higher MWD compared with that of the lower. Similar trends from the actual experimentation have been reported in the literature. Although the relations developed estimated CE were closer to the actual experimental results, there is a need to couple it with determination of soil water profiles involving redistribution and drainage characteristics of the soil for field conditions and rainfall pattern.

References

Boesten, J.J.T.I. and Stroosnijder, L.1986.Simple model for daily evaporation from fallow tilled soil under spring conditions in a temperate climate. *Neth. J. Agric. Sci.* **34** : 75-80.

Gill, B.S. and Jalota, S.K.1996. Evaporation from soil in relation to residue rate, mixing depth, soil texture, and evaporativity. *Soil Tech.* **8** : 293-301.

Jalota, S.K and Prihar, S.S.1986. Effect of atmospheric evaporativity, soil type, and redistribution time on evaporation from bare soil. *Aust. J. soil Res.* **24** : 357-366.

Jalota, S.K., Prihar, S.S. and Gill,K.S.1988. Modified square root of time relation to predict evaporation trends from bare soil. *Aust. J. Soil Res.* **26** : 281-289.

Jalota, S.K. and Prihar,S.S.1990.Effectiveness of tillage-induced soil mulch as influenced by soil type and atmospheric evaporativity. *J. Indian Soc. Soil Sci.* **38** : 583-591.

Jalota, S.K. and Prihar, S.S. 1992. Liquid component of evaporative flow in two tilled soils. *Soil Sci. Soc. Amer. J.* **56** : 1893-1896.

Jalota, S.K. and Prihar, S.S. 1998. Reducing soil water evaporation by tillage and straw mulching. IOWA State University Press, Ames, (U.S.A.)

Mwendera, E.J. and Feyen, J. 1997. Tillage and evaporativity effects on the drying characteristics of a silty loam: evaporation prediction models. *Soil and Till. Res.* **41** : 127-140.

Prihar, S.S., Jalota, S.K. and Steiner, J.L. 1996. Residue management for evaporation reduction in relation to soil type and evaporativity. *Soil Use and Manag.* **12** : 150-157.