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Simple Equations for Estimating Reference Evapotranspiration in an Arid Climate, Saudi Arabia

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ABSTRACT. Simple equations, based on easily available climatic data, were developed for the reference evapotranspiration (ET) in an arid climate of Saudi Arabia, taking 20 cm-tall alfalfa as a reference crop. These equations could be used in conjunction with crop coefficients to estimate the crop water requirements in irrigation practice, research work and computerized irrigation systems. The study was carried out with four non-weighing, freely drained, steel lysimeters having an actively growing dense cover of alfalfa, and surrounded on all sides by an alfalfa belt. The crop was frequently irrigated and the evapotranspiration was obtained by balancing the water inputs and outputs to the lysimeters. Equations based on the most important climatic variables were then fitted to the data.

Knowledge of crop evapotranspiration is extremely important in optimizing the use of available water for irrigation. Various approaches to the problem of predicting the water needs of crops have been proposed. Some of them need specialized instrumentation, are cumbersome in use and do not easily forecast the needs of areas where the climatic data used are not available (Yaron *et al.* 1973).

A large number of empirical equations (some having a good physical basis) exists for the estimation of evapotranspiration, *viz:* Penman (1948), Thornthwaite (1948), Blaney and Criddle (1950), Hargreaves (1956), Turc (1961), Jensen and Haise (1963), Rijtema (1965, 1969) and Priestley and Taylor (1972), etc. Modified forms of some of these equations are also available. The modified form of the Penman equation, most commonly used nowadays, is given by Hansen *et al.* (1980). It consists of an advective energy term in addition to the radiant energy. Another modified form of this equation was given by Doorenbos and Pruitt (1977), using an overall correction factor based on humidity and wind conditions. The use of this method for the estimation of evapotranspiration has been discussed in detail (Saeed and Abdel-Aziz, 1985). The modified forms of the Blaney Criddle method include the USDA-SCS correction (U.S.D.A. 1967) and the FAO method (Doorenbos and Pruitt 1977). Empirical coefficients are needed with the equations of Blaney and Criddle (1950), Turc (1961), Jensen and Haise (1963), and Hargreaves (1956) to estimate the evapotranspiration in desert areas (Saeed 1986). The equations of Thorthwaite (1948), Rijtema (1969), and Priestley and Taylor (1972) need evaluation before they could be put to use for the estimation of evapotranspiration in hot and arid climate. Rijtema's equation is similar to the Penman Equation with a major difference that it incorporates the effect of crop roughness in relation to crop height.

The objective of this study was to evaluate Rijtema, Priestley and Taylor, and Thornthwaite's Equations for possible use under arid conditions and hence develop simple equations from the 5-yr local data, for arriving at the reference evapotranspiration, with minimum meteorological data.

Materials and Methods

The study was conducted on four, non-weighing type, steel lysimeters, 2 × 2 × 1.25 m in size, at the Research Station of Agricultural College, King Saud University, situated in Dirab. The soil from the site was excavated and subsequently replaced in the lysimeters, so that the original soil profile was reconstructed and the bulk densities were approximately equal. A gravel layer of about 20 cm was provided at the bottom to facilitate drainage. The average depth of soil in the lysimeters was 95 cm. An underground passage was provided to facilitate access to the drainage water, which was allowed to drip out freely, and received in semitransparent plastic cans, calibrated to measure the water.

The field capacity and wilting point were determined on soil samples taken from the lysimeters, using a pressure membrane apparatus in the laboratory. The average values were 15.0% and 7.1% respectively.

A full cover of alfalfa was established in the lysimeters, situated in the middle of the Research Station with a cropped area of more than 100 hectares. The guard rings also carried an active growth of alfalfa and had an area of about 0.1 ha. The alfalfa in the belt was maintained under the same conditions and cut simultaneously with that in the lysimeters. It was cut manually to 5 cm when about 20% flowers appeared, and allowed to grow.

The irrigation water was applied by flooding, through calibrated water meters. Soil moisture measurements were made regularly each week. A soil core was taken with a sampling tube and moisture contents determined by the gravimetric method. The bulk density value, measured at different moisture contents, and the volumetric soil water profile were integrated to arrive at the total water stored in the soil profile.

Evapotranspiration was obtained from the crop as a difference between the input of irrigation water and rain (if any), less water storage changes and drainage water output. These values of ET correspond to the potential evapotranspiration rates as conditions of full cover and adequate water supply were maintained throughout.

The meteorologial data were obtained from a weather station bordering the lysimeter plot. Records of air temp, measured twice daily, wind speed on pan and two meter height, humidity, solar radiation, duration of sunshine, pan and Piche evaporation were available.

The following methods were used in the study:

1. Thornthwaite Method (Thornthwaite, 1948)

According to this method

$$E = 16.0\ (10\ T/I)^{a}$$

E = unadjusted potential evapotranspiration, in mm/month

T = monthly mean temperature, °C.

I = heat index for the 12 months in a year, where

$I = \Sigma i = \Sigma\ (T/5)^{1.514}$ for each month in the year

$a = 6.75 \times 10^{-7}\ I^3 - 7.71 \times 10^{-5}\ I^2 + 1.792 \times 10^{-2}\ I + 0.49239$

The values obtained are multiplied by factors, available from tables (Withers and Vipond 1974), for the month and latitude to get the adjusted values.

2. Rijtema equation (Rijtema 1964 and 1969)

In this method

$$E = \frac{\delta H_n + 10\gamma f(Z_0,d)\ u^{0.75}\ (e_s - e_d)}{\delta + \gamma\ [1 + 10.f(Z_0,d)\ u^{0.75} r_c]}$$

where

E = estimated evapotranspiration at any crop height in mm day^{-1}.

δ = slope of temp-vapor pressure curve in k $Pa°C^{-1}$

H_n = net radiation, mm day^{-1} = $(1-\alpha)\ H_{sh} - H_1$

α = shortwave reflection coefficient, was taken 0.24

H_{sh} = short wave radiation in mm day^{-1}

H_1 = net longwave radiation in mm day^{-1}

γ = Psychrometric constant, in $kPa°C^{-1}$ = $C_pP/0.622L$

C_p = 1.013 kJ kg^{-1}°C^{-1}
P = atmospheric pressure = 0.1 (1013 − 0.1055H) kPa
L = latent heat, kJ kg^{-1}
H = height above sea level = 296 m
Z_0 = roughness length of the evaporating surface, cm.
d = zero plane displacement in relation to the ground, cm.
u = wind velocity at 2 m height, cm s^{-1}
e_s = saturated vapor pressure in kPa at mean air temp.
e_a = actual vapor pressure, in kPa.
r_c = surface diffusion resistance in kPa day^{-1} mm^{-1} was taken as zero (maximum water use under full cover conditions.

f (Z_0,d) was determined from charts corresponding to the crop height measured during the period Rijtema 1965).

3. Priestley and Taylor Equation (Priestley and Taylor 1972)

According to this equation

$$E = \alpha \frac{\delta}{\delta+\gamma} (R_n - G)$$

E = Evapotranspiration in mm day^{-1}
α = Priestley-Taylor Coefficient = 1.26
δ = slope of temp-vapor pressure curve in kPa°C^{-1}
γ = psychrometric constant, kPa°C^{-1}
R_n = net radiation, mm day^{-1}
G = soil heat flux, mm day^{-1}

Results and Discussions

The variation of ET/E_A (*ie.g.* ratio of potential ET to evaporation from class A pan), during different growth cycles, is shown in Fig. 1. The ratio varies with the stage of growth and changes in meteorological conditions. The rate of change is higher in summer than in winter. The peak values attained are also greater in summer and reach a maximum of 0.95. Maximum values of the ratio occur soon after cut and maximum values occur when alfalfa is in the flowering stage. Thus, the ET (evapotranspiration) soon after cut will result in minimum ET/E_A ratio and hence is called ET_{min} for convenience. In the same way, the ET at the flowering stage is called ET_{max}. The values of ET_{min}, ET_{max} and ET_{20} (*i.e.* evaporanspiration from 20 cm tall falfalfa), at any instant, can be determined from E_a data at that instant. If desired, the ET corresponding to any intermediate stage, at any instant can be determined by interpolation from these values or more accurately from Fig. 1 and E_A data. In other words, the ET at any stage can be easily expressed in terms of ET_{20}, at that instant.

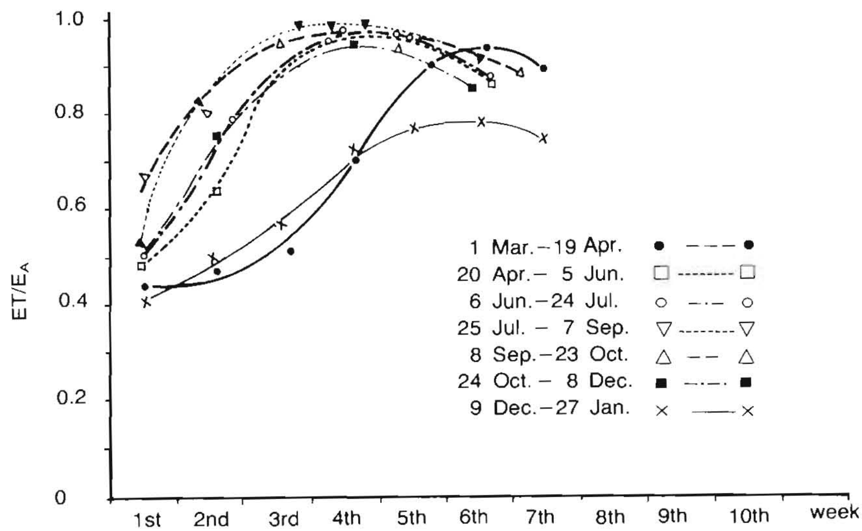

Fig. 1. The change in ET/E_A ratio in different seasons

Figure 2 shows the relationship between the measured ET and evaporation from class A pan. ET_{min}, ET_{20}, and ET_{max} are labelled separately. The relationship between ET_{20} and E_A is:

$$ET_{20} = 0.80\ E_A \cdots\cdots r = 0.95$$

The mutual relationships between ET_{min}, ET_{20} and ET_{max} are given as follows:

$$ET_{min} = 0.65\ ET_{20}$$
$$ET_{max} = 1.25\ ET_{20}$$

The estimates of evapotranspiration, given by the Thornthwaite and Priestley & Taylor Equations were plotted against the measured values of evapotranspiration from alfalfa and reduced to a reference height of 20 cm (Fig. 3). The figure shows that both these methods considerably underestimate the high rates of evapotranspiration found under arid conditions. The Thornthwaite Equation is based principally on temperature which is not a good indicator of the energy available for the evapotranspiration process. However, the method is simple and could be easily used to find out the evapotranspiration estimates, with the empirical coefficients given by the following equation:

$$ET = 0.98\ E_{Th} + 2.9 \cdots\cdots r^2 = 0.89$$

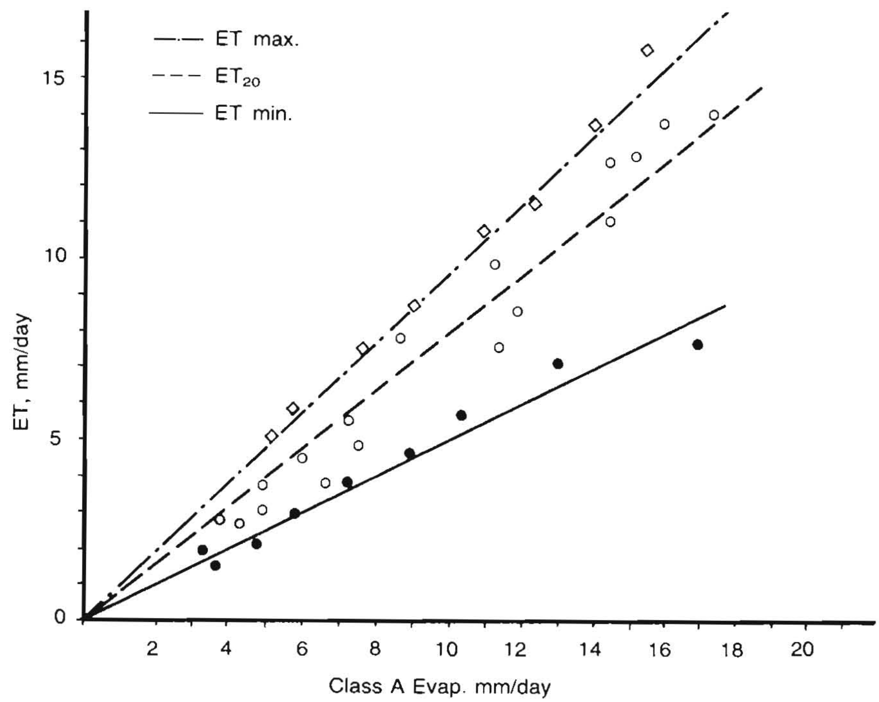

Fig. 2. The relationship between actual ET and evaporation from class A pan.

Where ET is the estimate of evapotranspiration and E_{Th} is the estimate obtained with the Thornthwaite Equation.

The Priestley & Taylor Equation does not include any advective energy term, but if the radiant energy as given by Penman is taken out from the equation, the remainder is seen to compensate for the advective energy to the extent of 26% of the radiant energy. The advective energy term, however, was found to range between 50% to 300% of the radiant energy, under the arid conditions found here. Hence the Priestley & Taylor Method results in underestimation. Suitable coefficients are needed with the equation for improved estimates. The following equation could be used:

$$ET = -2.12 + 2.87\ E_{PT} \cdots\cdots\ e = 0.97$$

where ET is the improved estimate and E_{PT} is the estimate obtained from the Priestley & Taylor Equation.

The measured ET data are shown in comparison to the estimates of evapotranspiration from Rijtema's Method, taking the surface diffusion as zero, in Fig. 4. Since the ET estimate from Rijtema's method (Tijtema 1965 and 1969) is

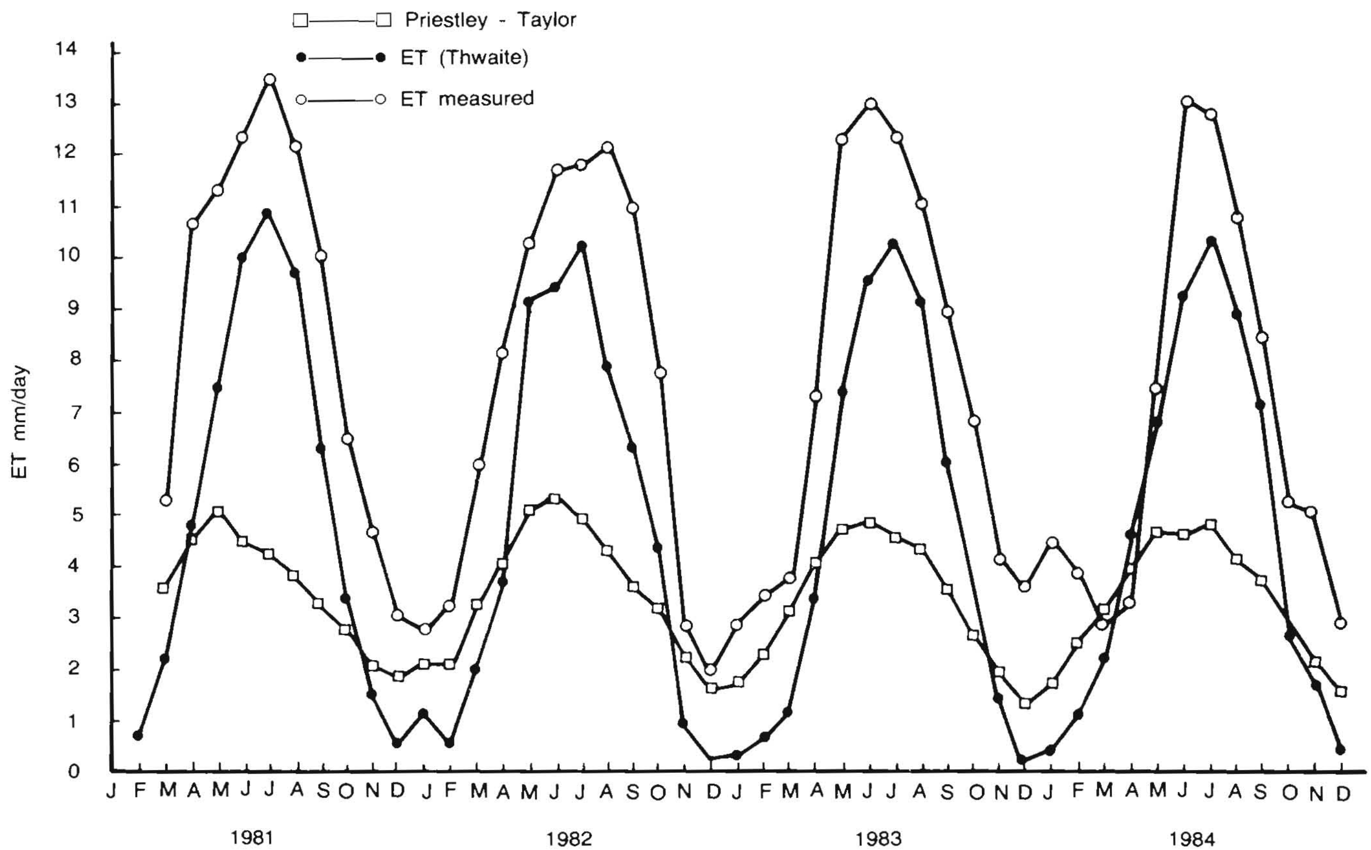

Fig. 3. Monthly ET estimates from Thornthwaite and Priestley & Taylor as compared to ET measured from alfalfa and reduced to 20 cm height

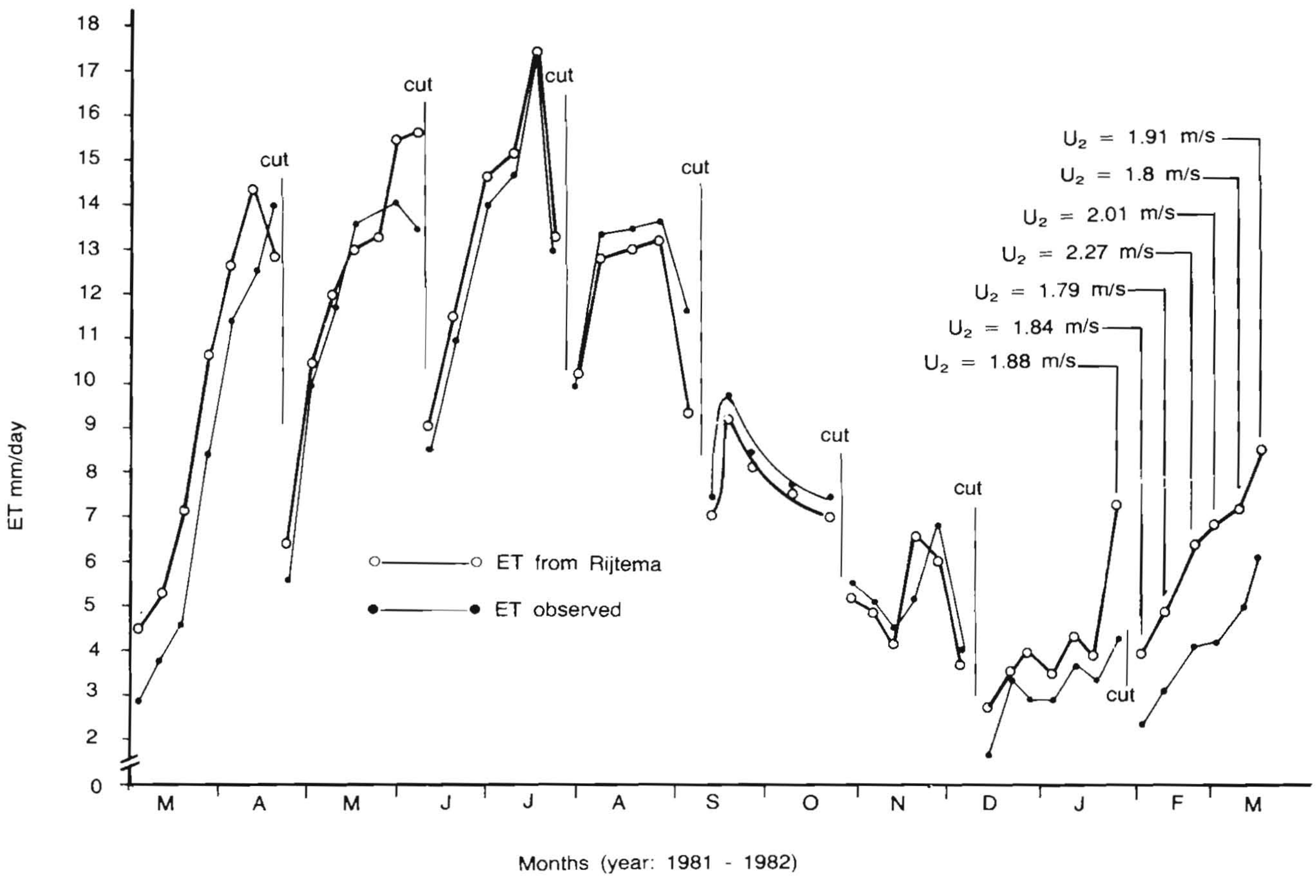

Fig. 4. The comparison of ET estimates from Rijtema to the measured ET in different seasons.

based on crop roughness height, it can be determined for any crop height. Thus, it can be easily compared to the measured ET from an alfalfa stand, during a growth cycle, as reduction of the ET to a reference height of 20 cm is not required. The figure shows that this method gives fairly good estimates of evapotranspiration in summer and some of the winter months. The ET is considerably overestimated in February and March, which is unexpected, as the data agree nicely in other months. To look further into the matter, the data for another year were added (Fig. 5). This figure shows that only a few cases of overestimation exist and that the overestimation, noted previously in February and March is within reasonable limits here. It was observed that the overestimation commonly takes place in cases where the wind speed (at 2 m height) is greater than 1.6 m s^{-1}. Best estimates are obtained for wind speeds below 1.5 m s^{-1}. Wind speeds have been defined low when less than 2 ms^{-1} and moderate when from 2 to 5 m s^{-1}. However, in this case, it seems that the wind speed starts to exert its influence, at lower speeds, *i.e.* in the vicinity of 1.75 m s^{-1}. Consequently, the vapor transport coefficient, $f(Z_0,d)$ $u^{0.75}$, gives higher values resulting in overestimation. In absence of data, taken in this direction, it is difficult to suggest any correction factor for higher wind speeds. Thus, the Rijtema's method can be used for the estimation of evapotranspiration, under arid conditions with 2 m wind speeds less than 1.75 m s^{-1}.

Most of the methods for ET estimation either involve very many meteorological data, use of charts and tables, or must be supplemented by modified coefficients to get improved estimates of evapotranspiration under arid conditions of Saudi Arabia. This is usually not convenient. To arrive at simple and yet appropriate equations, the measured data, collected during the years 1981 to 1985 (163 values) were computerized. An equation of the type: $A.H + B.T_a + C.\phi$ was assumed to completely describe the ET process, where H accounts for the radiation term and T_a (air temperature) and ϕ (relative humidity) are selected to describe the aerodynamic term when accompanied with suitable coefficients. These coefficients are determined and consequently the following equation was obtained:

$$ET_r = 0.5\,H + 0.35\,T_a - 3.5\,\phi$$

where

H = Short wave incident radiation, expressed in mm day^{-1}
T_a = Air temp, °C
ϕ = Relative humidity expressed decimally.
ET_r = The reference evapotranspiration in mm day^{-1}

The regression between the measured value of potential evapotranspiration, y and the calculated (or estimated) value of ET or ET_r, x, is given by:

$$y = 1.005 \times - 0.02 \cdots\cdots r = 0.8$$

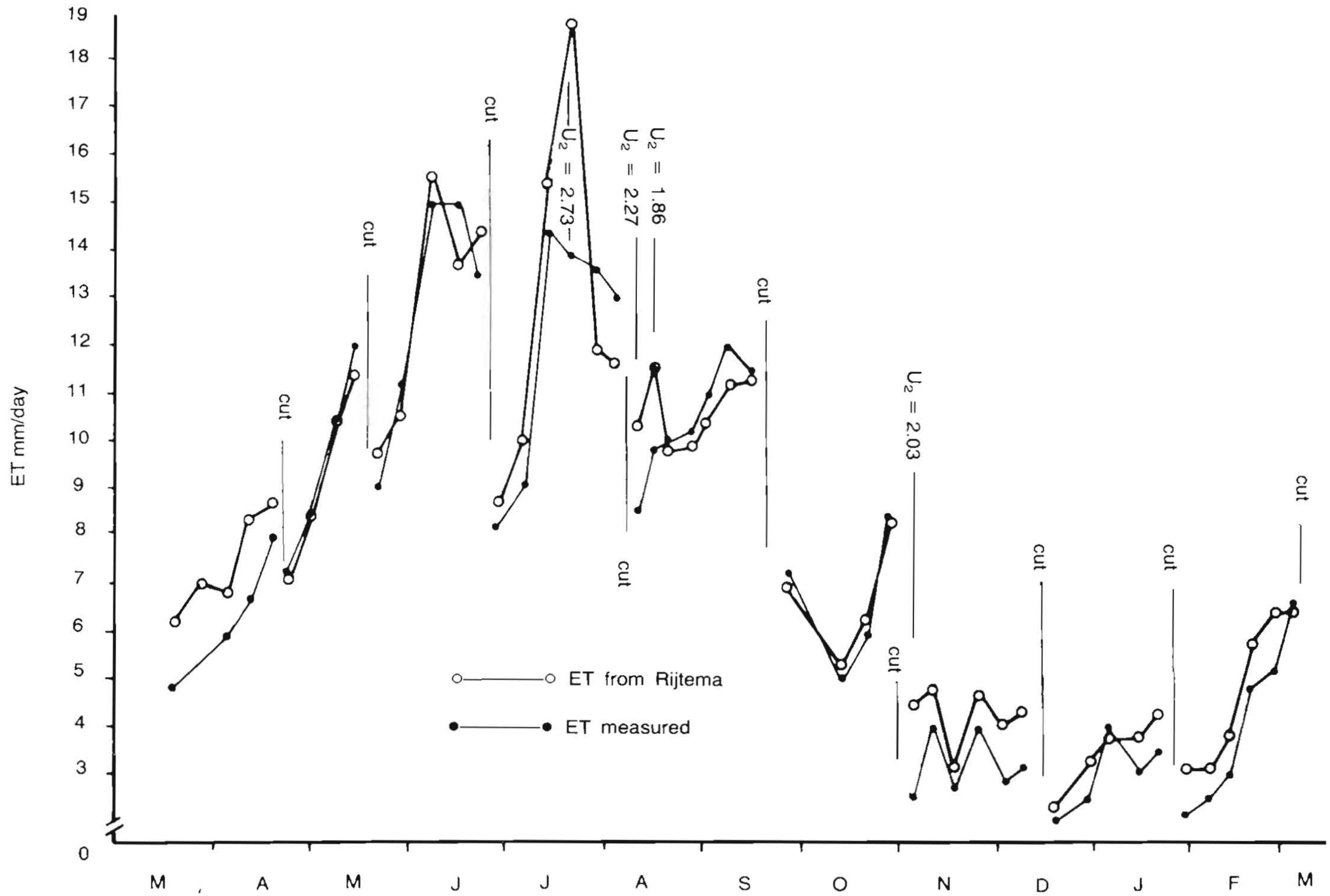

Fig. 5. The comparison of ET estimated from Rijtema to the measured ET in 1982-1983.

The intercept is very small and the slope of the line is about 1.Hence, this equation can be used for the ET estimation purposes advantageously.Usually, the radiation data are not available and cannot be measured easily. Instead, a U.S.W.B.class A pan or Piche evaporimeter is much cheaper and easier to install and use.Hence, the ET in relation to these evaporation rates may be more useful. The following equations are obtained:

$$ET_r = 0.8\ E_A \cdots\cdots\cdots r = 0.94$$

$$ET_r = 0.80\ E_P - 0.12 \cdots\cdots\cdots r = 0.80$$

Where E_A and E_P are the pan and Piche evaporation rates.

If only the temperature data are available, the ET can be estimated from the following equation:

$$ET_r = 0.42\ T_a - 2.61 \cdots\cdots\cdots r = 0.82$$

Obviously, the equation will give negative values at lower temperatures, and hence should not be used in such cases.

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Appendix 1

Table 1. Mean Monthly Meteorological Data at Dirab

Month	Temperature C		Relative Humidity		Solar Radiation	Sunshine duration	wind speed	pan evap.
	Max	Min	Max	Min	$MJ\text{-}M^{-2}$	Hr	$m\ s^{-1}$	mm/day
Jan	21.78	5.95	75.6	27.9	13.90	7.86	1.104	4.57
Feb	23.09	7.66	66.1	29.0	16.07	7.99	1.332	5.79
Mar	26.82	13.00	62.0	26.3	17.24	7.35	1.584	7.67
Apr	33.49	18.17	50.7	20.0	19.34	7.96	1.498	10.25
May	38.73	22.53	42.3	19.6	20.35	7.53	1.502	13.66
June	41.45	23.30	28.5	14.8	22.24	9.72	1.836	16.20
July	42.29	24.44	24.9	13.4	22.55	10.20	1.527	15.30
Aug	41.00	23.18	28.3	13.9	20.75	9.57	1.532	14.73
Sep	39.45	18.41	31.0	14.1	19.60	9.53	1.080	11.92
Oct	33.57	14.53	48.1	18.9	17.45	9.02	0.763	7.99
Nov	26.88	10.58	61.3	26.1	14.63	8.05	1.135	5.93
Dec	21.19	6.17	77.5	32.4	12.81	7.29	0.981	3.99

معادلات مبسطة لتقدير البخر ـ نتح، لنبات البرسيم في ظروف المناطق الحارة الجافة من المملكة العربية السعودية

محمد سعيد حضرت

قسم الهندسة الزراعية ـ كلية الزراعة ـ جامعة الملك سعود ـ ص . ب ٢٤٦٠ الرياض ١١٤٥١
المملكة العربية السعودية

تم تطوير معادلات بسيطة مبنية على بيانات مناخية سهل الحصول عليها لجهد البخر ـ نتح . وقد أخذ نبات البرسيم كمحصول مقارنة تحت ظروف المناخ الجاف للمملكة العربية السعودية . هذه المعادلات بربطها بمعامل المحصول يمكن استخدامها في تقدير الاحتياجات المائية للمحاصيل المختلفة، عند القيام بعمليات الري الحقلي أو الأعمال البحثية أو نظم الري المبرمجة .

ويعتمد تقدير الاستهلاك المائي لأي محصول بدقة على البخر ـ نتح المقارن .

ان معادلات البخر ـ نتح المتداولة لا تعطي تقديراً صحيحاً للبخر ـ نتح في المناطق الجافة وتحتاج إلى تعديل .

وبدلاً من استخدام معاملات جديدة مع هذه المعادلات فالأفضل وضع معادلات بسيطة ـ بجمع البيانات المناخية وللبخر ـ نتح ـ التي تعطي مباشرة البخر ـ نتح المقارن .

لقد تمت الدراسة في أربع ليسومترات معدنية غير موزنة، والصرف فيها حرا، ومزروعة بالبرسيم بكثافة فعالة، ومحاطة من جميع جوانبها بحزام من نبات البرسيم .

كان المحصول يروى بانتظام، ويحسب البخر ـ نتح من موازنة الماء الداخل والماء الخارج من الليسومترات . وتم الحصول على البيانات المناخية من محطة أرصاد نموذجية .

ان طريقة جمع البيانات للمحصول المقارن نوقشت، واختبرت الطريقتان المزدوجتان لايجاد البخر ـ نتح .

وأخيراً اعتمدت المعادلات على أهم العناصر المناخية المتغير لفترة خمس سنوات .

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A Proposed Method to Reduce the Influence of Chloride on Soil Moisture Determination by the Neutron Meter

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ABSTRACT. An investigation was conducted to study the effect of chloride concentration on moisture determination by the neutron meter in salt affected soil. Statistical tests indicated that the errors in estimated soil moisture content (θv) values increased with increases in chloride concentration for a given soil. This trend was most noticeable at low moisture contents where deviations up to +20.7% were observed.

A regression equation was formulated to correct the readings of the neutron meter for a range of chloride concentrations in soil. The method lowered the average deviation of estimated θv from approximately 11.8 to 2.4%.

Neutron meter soil moisture measurement have been widely used in the last three decades. The neutron being discovered in 1931 by Chadwick (1932) has a readily detectable and strong interaction with material rich in protons such as water. The principles of this method were well stated by Van Bavel *et al.*, 1963; however, the neutron moisture meter has several advantages and disadvantages (Benz *et al.* 1965). Some of the important advantages are: (1) the large sample size improves accuracy if the meter is properly calibrated; (2) volumetric water content can be obtained directly; and (3) successive measurements can be taken at the same location. On the other hand the disadvantages reported by several workers such as Holmes and Jenkinson (1959), Knight and Wright (1954) and, Van Bavel *et al.* (1961) were that different soils have different calibration curves and careful consideration should be given to field calibration of the instrument for each soil type.

Soil elements such as chloride, boron and iron may affect the relationship between thermal neutron activity and soil moisture content. Benz *et al.* (1965) indicated that the field calibration curves obtained in saline soils deviated from those obtained under non-saline conditions. Holmes (1966) found that change as small as 0.74% (w/w) for Cl and 100 ppm for B may change the slope of the calibration curve by 10%.

In many arid and semi-arid areas, salts such as Nacl, $MgCl_2$, $CaCl_2$ and $MgSO_4$ may accumulate in large amounts in agricultural lands. Thus Cl ions may be a large constituent of the soil, and its effect may give erroneous results. Consequently, this study carried out to find the effect of Cl concentration on the calibration curves of the neutron meter and to investigate the possibility of reducing the resulting errors in soil moisture measurements under saline conditions.

Materials and Methods

The neutron moisture meter used in this study was manufactured by Troxler Electronic Laboratories (Type 3222). Containers, 70 cm deep and 60 cm inside diameter were filled with either salt solution or salinized soil. Salt solutions that ranged in concentration from 300 to 53200 ppm of 1:1:1 ratio of NaCl, KCl, and $CaCl_2$ were used to obtain the neutron meter readings in the containers. Five readings of one minute duration were recorded for each concentration.

The soil samples were taken from 0-30 cm at three different locations, Fudhalia (vertic torrifluvent), Jadriah (Typical torrifluvent) and Ishaki (vertic torrifluvent). Texture analysis for the three soils are shown in Table 1. The soils were passed through a 4 mm seive and brought to the desired moisture content and Cl concentration by applying water and the required Cl solution with a sprayer. The soil was thoroughly mixed by hand to achieve uniform moisture and salt distribution. The soils were then packed into the containers in 10 cm increments. The moist soil in each layer was weighed and mechanically packed to give uniform bulk density and moisture content. Gravimetric moisture content was determined

Table 1. Soil texture and soil moisture saturation % of the investigated soils

Soil	Sand %	Silt %	Clay %	Texture	Soil moisture saturation % (w/w)
Jadriah	62.0	27.0	11.0	sandy loam	36.0
Ishaki	7.2	42.0	50.8	silty clay	48.5
Fudhalia	15.2	39.0	45.8	clay	47.2

independently for each moisture content level. One minute count readings were replicated five times for each container. The readings for this study were taken at 15 cm from the bottom of each container using 3 mm wall thickness galvanized access tubes. The soil treatments consisted of five different Cl concentrations and six soil moisture levels (θv).

Results and Discussion

The relationship between count ratio (CR) and Cl concentration in solution using NaCl, $CaCl_2$ and KCl is presented in Fig. 1. The data indicate that the CR increased linearly with a decreasing Cl concentration. A correlation coefficient of −0.97 is representative of a best fit relation in the following equation:

$$CR = 1.21 - 1.60 \times 10^{-5}\,Cl \quad (1)$$

where Cl is in ppm.

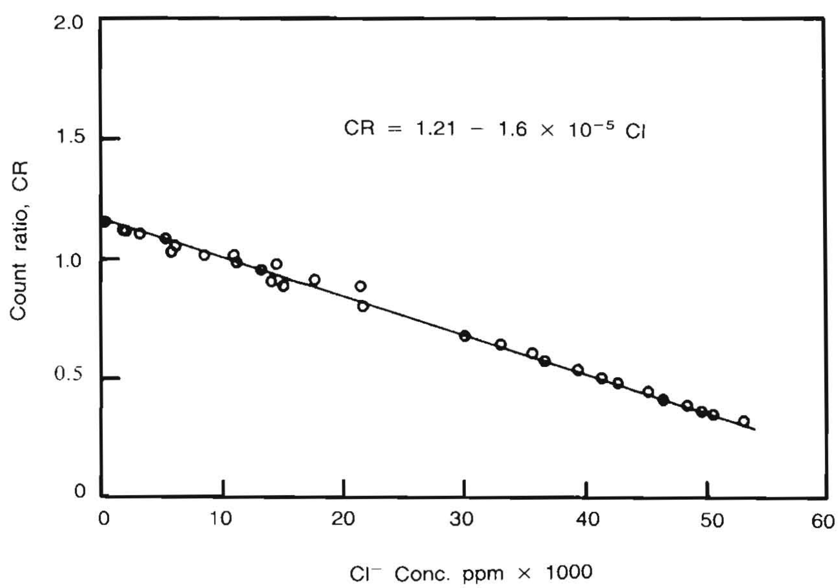

Fig. 1. The relationship between Cl^- concentration in solution and count ratio (CR).

Coefficients for the regression equations of the calibration curves for the three different soils at various Cl concentration and their correlation coefficients are presented in Table (2). The chloride concentration varied between 85 and 4532 ppm in the saturated extract of the three soils. The linearity of the relationship between CR and θv given by 15 correlation coefficients of 0.99 or higher appears to be valid for the θv range used in this study. The data are pooled for each soil and the regression coefficients are obtained and given in Table 2. Statistical analysis between b values of different Cl concentrations with b of pooled data of each soil indicate a significant differences (P = 0.1) when Cl concentration is greater than 2000 ppm. The departure in θv increases as the Cl concentration increases for all three soils. Therefore, it is necessary to take into account the decrease in neutron meter counts due to the presence of Cl in the soil. Similar results were reprorted by Benz *et al.* (1965). However, it is not practical to have a calibration curve for each chloride concentration for a given soil; therefore, the following equation is proposed to correct the neutron meter count reading:

$$\theta v = a + b\,(CR + b' \times Cl) \tag{2}$$

where:

θv = volumetric water content (v/v)
CR = count ratio of the neutron meter
Cl = chloride concentration of the saturated extract in ppm.
a = intercept
b = slope of θv *vs.* CR for a given soil at non saline conditions.
b′ = Slope of CR *vs.* Cl in solution

The values of a and b are regression parameters for any given soil at low Cl concentration (nonsaline conditions) and representative of the first entry for each soil in Table 2. The value of b′ is a regression parameter of the calibration curve for Cl solution as shown in Figure 1 and given by equation (1).

A comparison between measured and predicted moisture contents using the first a and b values (Table 2) for the three soils with and without correction term for Cl concentration (Eq. 2) is presented in Table 3. The deviations in θv varied from + 0.3 to 20.7% before correction and from −0.4 to 7.7% after correction for Cl concentration. The higher the Cl concentration, the greater is the deviation in θv. This is more pronounced at drier soil conditions. Therefore, a correction for Cl concentration in θv estimation using the neutron meter is required for more accurate water determinations. Statistical analysis indicated no significant differences between measured and estimated θv after correction for Cl concentration.

The data are pooled for the three soils and the regresion coefficients are obtained and presented in Table 2. The t-tests between the b value of the pooled data for the three soils and b values of the pooled data for each soil indicated that the calibration curve of the Jadriah soil (sandy loam) is significantly varied from the calibration curves of the other two soils. The clay contents of the Jadriah, Ishaki and Fudhalia soils were 11, 50.8 and 45.8%, respectively. The rate of change in θv with respect to CR for the three soils used in the study was in the

Table 2. Regression and correlation coefficients for soil moisture as a function of the CR at five Cl concentration for the three soils

Soil	Cl conc. (ppm)	a	b	Correlation coefficient
	187	3.02	53.88	0.991
	2228	1.96	56.60*	0.990
Jadriah	2588	3.60	56.09*	0.998
	3020	4.05	56.06*	0.995
	3666	3.86	56.60*	0.995
	pooled	3.95	54.86**	0.988
	82	2.49	48.77	0.993
	767	3.75	46.80	0.988
Ishaki	1422	3.30	48.44	0.990
	2215	2.79	51.54*	0.995
	4532	4.64	49.07*	0.993
	pooled	3.62	47.64	0.974
	415	0.24	48.98	0.998
	2050	3.17	45.50*	0.999
Fudhalia	2367	1.46	49.26*	0.995
	3090	1.83	48.97*	0.997
	3490	2.42	49.10*	0.993
	pooled	2.41	46.47	0.971
Pooled date for the three soils		4.44	46.32	0.957

* Significant variations between the b value of the pooled data and b values of different Cl concentration for a given soil.

** Significant variations between the b value of the pooled data for the three soils and b value of a given soil.

order: sandy loam > silty clay > clay. Similar results were reported by Holmes (1966) whereas contrary results were found by Shirazi and Isobe (1976). The latter, however, used soils of widely different mineralogy. Therefore, the neutron meter should be calibrated for each soil.

Conclusions

Results of this study indicate that the accuracy of soil moisture measurements with the neutron meter is greatly influenced by high Cl ion concentration. Calibration curves obtained from salt solution and from artificially-salinized soil materials deviated widely from curves of non-saline conditions. The deviation in values of θv due to the presence of Cl was as high as 20.7% for the highest Cl concentration. For the Cl concentration (<2000 ppm) normally found in cultivable saline soils do not significantly influence volumetric moisture content determination by the neutron meter, but the deviation increased as Cl increased and the soil became drier. A method is proposed to correct the neutron meter readings for the effect of Cl ions in soils. By using this method, the deviation of estimated values of θv from measured values were reduced to 0.4 to 3.0% range.

Table 3. Comparison between % deviation in θv with and without correction for Cl concentration for the three soils

Cl (ppm)	CR	Dev. % without correction	Dev. % with correction
		Fudhalia soil	
	0.560	3.2	1.6
2050	0.395	4.3	2.3
	0.258	10.4	0.8
	0.528	6.4	0.6
2367	0.364	9.6	1.6
	0.250	10.7	0.7
	0.545	6.4	1.8
3490	0.371	11.0	0.4
	0.244	14.0	2.6
		Jadriah soil	
	0.464	0.3	5.1
2228	0.174	6.1	3.8
	0.074	12.0	4.2
	0.447	3.5	5.2
3020	0.171	10.0	4.0
	0.074	17.0	4.5
	0.429	6.4	2.2
366	0.153	11.2	7.7
	0.074	20.7	6.3
		Ishaki soil	
	0.414	6.6	0.4
2215	0.296	0.5	1.9
	0.170	7.9	5.2
	0.437	8.5	3.4
4532	0.289	12.3	4.0
	0.168	17.3	6.7

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طريقة لتقليل الخطأ في قراءات مقياس الرطوبة النيتروني الناتج لوجود آيون الكلور في التربة

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لقد شاع في العقود الثلاثة المنصرمة استخدام طريقة سريعة لتقدير رطوبة التربة وذلك باستخدام جهاز خاص يعرف بمقياس الرطوبة النيتروني، الذي من أبرز مميزاته هو إمكانية استخدامه في تقدير رطوبة التربة بدقة عالية وبصورة مباشرة فيما لو تمت معايرته بشكل جيد، إمكانية استخدامه كذلك في الحصول على قراءات متكررة لنفس الموقع وفي أوقات مختلفة.

لقد دلت الأبحاث أن لبعض عناصر التربة (كالكلوريد والحديد والبورون) تأثير واضح على دقة قراءات هذا الجهاز من خلال تأثيرها المباشر على النيوترونات التي يطلقها الجهاز. هذا وبالنظر إلى وجود آيون الكلوريد بنسب عالية في معظم الأراضي الزراعية (على الأخص في المناطق الجافة وشبه الجافة) ولغرض معرفة تأثير ذلك على منحنى معايرة هذا الجهاز، فقد جاء الهدف من هذه الدراسة.

استخدمت في هذه الدراسة حاويات بلاستيكية بقطر (٦٠) سم وبعمق (٧٠) سم. تم ملؤها بمحلول ملحي وبثلاث من الترب المختلفة، الأولى طينية (موقع الفضيلية) والثانية غرينية طينية (موقع الإسحاقي) والثالثة رملية مزيجية (موقع الجادرية)، وقد أشارت النتائج إلى وجود علاقة خطية بين قراءة الجهاز وتركيز آيون الكلوريد في المحلول بمعامل ارتباط (٠,٩٧ −)، وإلى وجود علاقة خطية كذلك بين هذه القراءة ورطوبة التربة لكل تركيز معين في الترب المختلفة بمعامل ارتباط يزيد عن (٠,٩٩). وقد تأكد أيضاً بأن لتركيز آيون الكلوريد الأثر الواضح على دقة قراءة الجهاز من خلال زيادة إنحراف منحنى معايرة الجهاز الذي

قد يصل إلى نسبة ٢٠٪ أو لربما أكثر عند زيادة تركيز آيون الكلوريد في التربة. أما بالنسبة للترب التي يقل فيها تركيز هذا الآيون عن ٢٠٠٠ جزء بالمليون فقد كان عندها مقدار الإنحراف غير معنوي من الناحية الاحصائية.

تم اقتراح صيغة احصائية مبسطة لتقدير رطوبة التربة في الأراضي التي يزيد فيها تركيز آيون الكلوريد عن ٢٠٠٠ جزء بالمليون. وقد تبين من خلال المقارنة بأن نسبة الخطأ الناتج في نسبة رطوبة التربة المقدرة بواسطة الجهاز قد إنحسرت بين (٠,٤ - ٧,٧) ٪. كما تبين أيضاً بأن طبيعة الإختلاف في منحنى معايرة الترب المختلفة النسجة قد كان معنوياً، وعليه باتت معايرة الجهاز للترب المختلفة النسجة أمراً ضرورياً.