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Reference Evapotranspiration Study in Al-Qassim Region

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Abstract. A comparison of four methods for estimating grass reference evapotranspiration, ET_0, are presented. The four methods are class A pan, Radiation, Jensen-Haise, and Penman. The Radiation method overestimated the other methods, but if the adjustment factor is to be taken equal to 0.9 the Radiation method would be close to the Jensen-Haise method. The derived seasonal average pan coefficient of 0.61 gives a more conservative value. The Penman method could be used with a local back radiation of 1.34 mm/day and an albedo for the cropped surface of 0.35.

Considering the problems associated with the availability and reliability of weather data and the possible errors in Penman and Radiation methods, the Jensen-Haise method calibrated for Al-Qassim region and presented in this study is recommended as the most simple and practical method for estimating ET_0.

Introduction

Center pivot sprinkler irrigation has expanded rapidly in Qassim for growing wheat. A major problem faced by irrigators is scheduling on low water holding capacity soils. Too much irrigation will leach valuable plant nutrients. On the other hand, too little irrigation can depress yields and profits. Accurate irrigation scheduling, based on sound scientific principles, is becoming more important each day as water supplies become scarce. Irrigation scheduling relies on modeling or measuring evapotranspiration to update the soil water balance and to forecast future water use to predict when the allowable depletion will be reached. Models using weather parameters to calculate evapotranspiration (ET) are used to schedule irrigations by a water budgeting process. Basically, some reference ET is used, ET_o for grass, ET_r for alfalfa, or E_p for pan evaporation, and crop ET_c is estimated by multiplying the reference ET by empirically derived crop coefficients.

Grass reference ET has been extensively used and is defined as the ET of well-watered, actively growing, green grass which is clipped to a uniform height of 8-15 cm, completely shading the soil, not short of water, and covering an extensive area [1 p. 156]. Short grass ET is less than alfalfa ET.The assumption was made that a constant ratio of 0.85 exists between grass and alfalfa reference ET [2 p. 227]. Various methods are available to estimate the ET for grass or alfalfa. Recently, a study [3 p. 332] evaluated 24 methods of predicting ET for both humid and arid regions.

The objectives of this study were to test some methods of estimating ET_o from climatic data as compared to the ET_o obtained from the evaporation measured by the class A pan.

Procedures and Methods

A computer program was written in BASIC to calculate the reference ET by class A pan, radiation, Jensen-Haise, and Penman methods using the weather data collected for the periods December 15 to April 30 of the years 1987/1988, 1989/1990, and 1990/1991, which are the wheat growing seasons. The weather data were collected from agrometreological station at the College of Agriculture farm in Buriedah, Qassim. Elevation and latitude of Buriedah are 625 m and 26° north.

1. Penman method

The modified Penman equation [4], [5 pp. 241-279] is

$$ET_o = (\Delta / (\Delta+\gamma)) (R_n+G) + (\gamma/(\Delta+\gamma)) f(u) (e_s - e_a) \qquad (1)$$

where:

- ET_o = reference evapotranspiration in mm/day
- Δ = slope of the saturation vapor pressure curve in kPa/°c at mean air temperature.
- γ = Psychrometric constant in kPa/°c.
- G = energy into the soil, generally assumed to be zero, mm of water/day.
- e_s = mean saturated vapor pressure in kPa (average of pressure at maximum temperature and at minimum daily air temperature).
- e_a = saturated vapor pressure at mean dew point temperature in kPa ($e_a = e_s$ * relative humidity).

According to Fritschen and Gay [6 pp. 55-81] and Hatfield and Fuches [7 pp. 33-54]:

$$e_s = 0.1 \exp[\,18.7209 - 3806/(T_a+273.1) - 222153/(T_a+273.1)^2] \tag{2}$$

while Δ can be given as:

$$\Delta = e_s[3806/(T_a+273.1)^2 + 444306/(T_a+273.1)^3] \tag{3}$$

where T_a is the air temperature in °C and

$$\gamma = [P/\lambda]/625 \tag{4}$$

and

$$\lambda = 2.510 - (T_a/423) \tag{5}$$

where λ is the latent heat of vaporization in MJ/kg. The change in barometric pressure, P (kPa), with elevation can be expressed as:

$$P = 101.3 - (E/95) \tag{6}$$

with E the elevation in m.

Net radiation energy, R_n, may be calculated from

$$R_n = (1-r)\, R_s - R_b \tag{7}$$

r = radiation reflection coefficient (albedo) of the surface (dimensionless fraction), albedo for a cropped surface ranges between 0.22 and 0.32 and was assumed to equal .25 in this study. The outgoing long-wave radiation R_b (mm water/day) is estimated as follows [8, pp. 81-86]:

$$R_b = \sigma\, T_K^4\, (0.56 - 0.092\sqrt{7.6\, e_a})\, (\varkappa + (1-\varkappa)n/N) \tag{8}$$

where

σ = Stephan Boltzman constant in equivalent evaporation unit

= 0.198×10^{-8} mm water.day^{-1} °K^{-4} (equivalent to 5.67×10^{-8} Jm^{-2}s^{-1} °K^{-4}).

T_k = absolute temperature °K

In Eq. 8 the later bracket is included to allow for the effect of cloud cover, the remainder giving the back radiation in a cloudless environment. Typical reported value of χ is 0.1.

According to Ture [9]:

$$R_s = R_a \,(0.29 \,\mathrm{Cos}\,(\mathrm{latitude}) + 0.54\, n/N) \tag{9}$$

where

n/N = the ratio of actual to possible hours of sunshine

R_s = the incoming radiation at the top of the atmosphere

R_a = the mean extra-terrestrial radiation in equivalent evaporation in mm water/day

In this study R_a and N were calculated from model equations for Buriedah fitted from tables provided by [1] as follows:

$$R_a = 8.3332 + 0.0536(DOY) + 3.5538E{-}4(DOY)^2 - 3.2069E{-}6(DOY)^3 + 5.039E{-}9(DOY)^4 \quad (R=0.9918) \tag{10}$$

$$N = 10.0812 + 0.036502\,(DOY) - 1.036848E{-}4\,(DOY)^2 \tag{11}$$

$$(R=0.96619)$$

where

DOY = day of year starting January, 1

The parameter in Eq. 1 which varies the most among researchers is the wind function, f(u) term, as discussed by Howell *et al.* [5] and Jensen [10, p. 215]. According to Doorenbos and Fruitt [1] the wind function for grass as reference crop is

$$f(u) = 2.70 + 2.33\, U_2 \tag{12}$$

where

U_2 = mean daily wind speed in m/s at 2 m height.

2. Jensen-Haise method

The original Jensen-Haise method was modified to adjust the coefficients for altitude and humidity index to increase the accuracy of the radiation balance method [11].

The modified Jensen-Haise method is as follows:

$$ET_0 = C\,(T_a - T_x)\,R_s \quad (13)$$
$$C = 1/(C_1 + 7.3\,C_h) \quad (14)$$
$$C_h = 5/(e_2 - e_1) \quad (15)$$
$$C_1 = 45 - (E/137) \quad \text{for clipped grass} \quad (16)$$
$$T_x = -2.5 - 1.4(e_2 - e_1) - E/550 \quad (17)$$

where

e_2 and e_1 are the saturated vapor pressure in KPa in the warmest months in an area at the mean maximum and mean minimum air temperature, respectively. Using Eqs.13 through 17, the Jensen-Haise equation derived in this study for Buriedah, Qassim is

$$ET_0 = (0.02\,T_a + 0.25)\,R_s \quad (18)$$

3. Radiation method

The grass reference ET according to the FAO radiation method is given by:

$$ET_0 = n\,W\,R_s \quad (19)$$

where

$$W = \Delta / (\Delta + \gamma)$$

n = adjustment factor [1].

The values of n are close to 1, so it is assumed to equal 1 in this study for simplicity.

4. Evaporation pan method

The relationship between ET_0 and measured pan evaporation, E_p, is given as:

$$ET_0 = K_p \cdot K_p$$

The K_p value represents the pan coefficient. The factors which influence the K_p value are found in detail in Doorenbos and Pruitt [1]. The data required for estimating K_p are pan surroundings, relative humidity, and mean wind speed in Km/day at 2 m height.

Results and Discussion

The four methods of estimating ET_0 for the three seasons are presented in Figs. 1 through 6. It can be seen from Figs. 1 and 2 that the radiation method is higher than the other methods for the 1988-1989 growing season. The same idea applies for the 1989-1990 season except that the class A pan shows the lowest ET_0 for 90 days after planting then it turned out to be the highest as shown in Figs. 3 and 4. In 1990-1991 season the highest ET_0 for the radiation method and the lowest for the pan are shown in Figs. 5 and 6.

It can be said that the radiation method overestimated the ET_0 and the pan underestimated the ET_0. Thus, if the adjustment factor n was taken equal to 0.9, instead of 1 as assumed, the radiation method would be close to the Jensen-Haise method which is also based on radiation balance. The pan coefficients varied between 0.6 and 0.65 during the three seasons with a weighted average of 0.61 according to the pan location and the input weather data during these periods. The pan coefficients were obtained from those given by Doorenbos and Pruitt [1].

The predicting ET_0 methods are highly correlated to the ET_0 (pan) as follows:

$$\text{Rad} = 2.228 + 0.5616\ \text{Pan} \qquad (R=0.9665) \tag{21}$$

$$\text{J-H} = 1.2348 + 0.6788\ \text{Pan} \qquad (R=0.9842) \tag{22}$$

$$\text{Penman} = 1.7925 + 0.5952\ \text{Pan} \qquad (R=0.9878) \tag{23}$$

From the computer output, the relation between R_s and R_n fitted the following linear equation;

$$R_n = 0.65\ R_s - 1.34 \qquad (R=0.9705) \tag{24}$$

If Eq. 24 is compared to Eq. 7, r would be equal to 0.35 and R_b would equal 1.34 mm/day. Equation 24 is useful in developing local values to facilitate the use of Penman method.

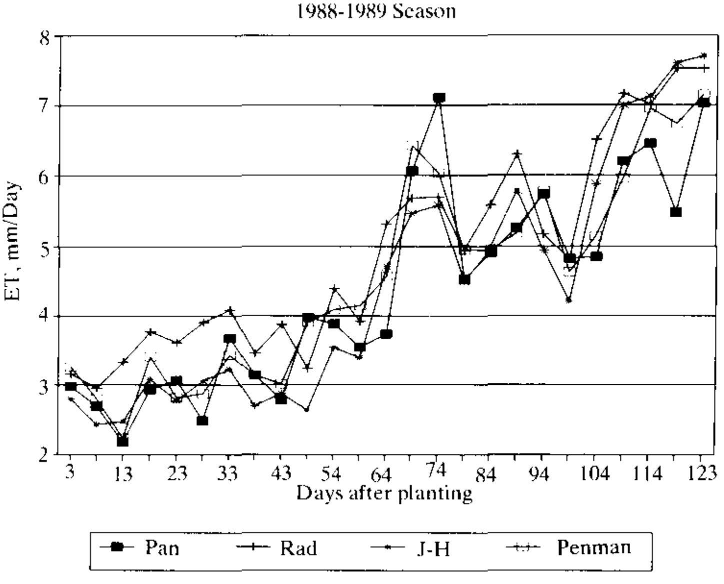

Fig. 1. Comparison of different methods of estimating daily ET_0 for 1988-1989 data.

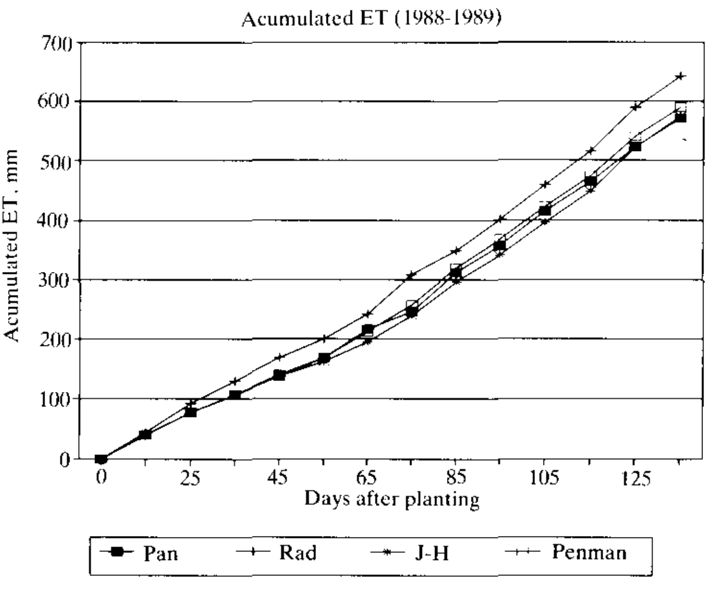

Fig. 2. Cumulative ET_0 calculated by different methods for 1988-1989 data.

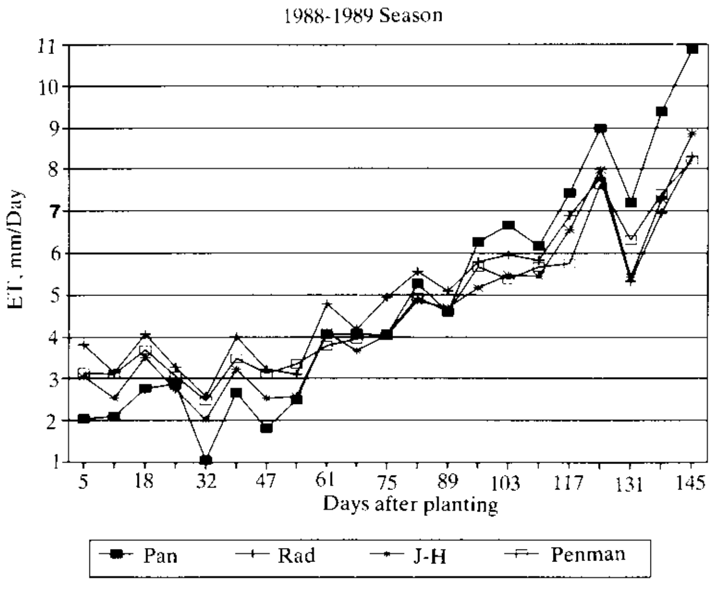

Fig. 3. Comparison of different methods of estimating daily ET_0 for 1989-1990 data.

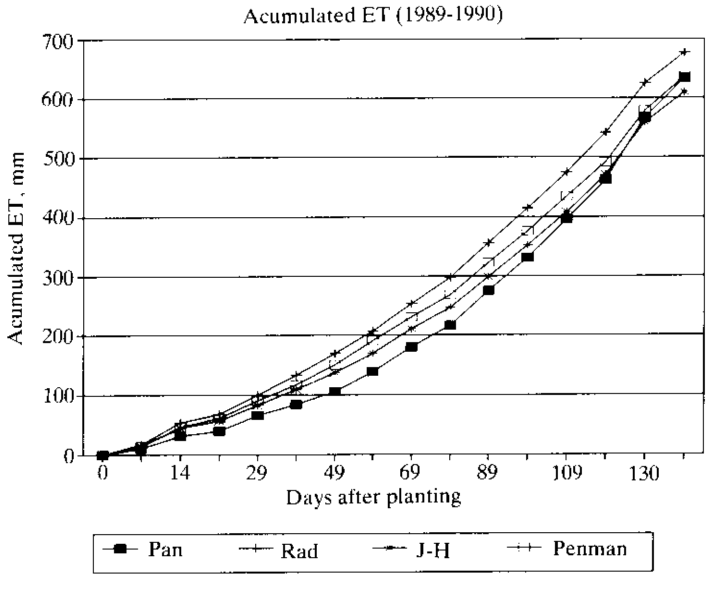

Fig. 4. Cumulative ET_0 calculated by different methods for 1989-1990 data.

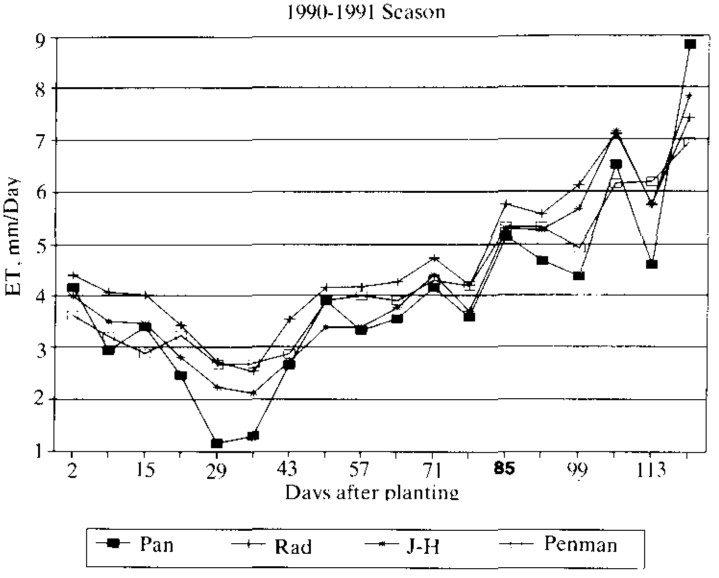

Fig. 5. Comparison of different methods of estimating daily ET_0 for 1990-1991 data.

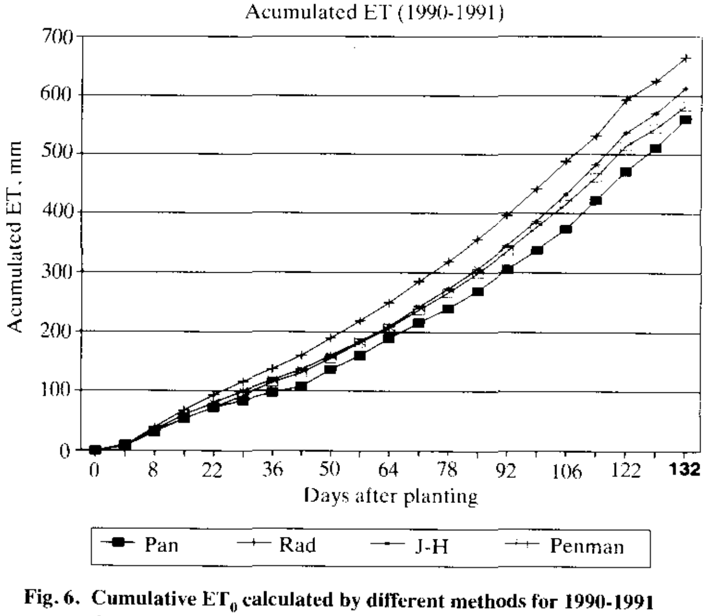

Fig. 6. Cumulative ET_0 calculated by different methods for 1990-1991 data.

Table 1 summarizes the cumulative ET_0 for the four methods during the period of December 15 to April 30 with daily input to the computer program. It can be seen that the radiation method overestimated the other methods and the class A pan underestimated the other methods especially during the 1990–1991 season which indicates that the values of pan coefficients were more conservative.

It can be said that all the methods tested in this study could be used in Al-Qassim region and can be simplified using the derived local constants. It can be concluded that the Jensen-Haise method calibrated for Al-Qassim and presented herein is recommended as the most simple and practical method for estimating ET_0.

Table 1. Estimates of grass reference ET_0,mm as calculated for the period December 15 to April 30 with daily inputs.

Season	Class A Pan	Radiation	Jensen-Haise	Penman
1988–1989	570	641.8	574.5	588.3
1989–1990	632.9	675.3	608.7	634.9
1990–1991	561	665	613	582.3
Average	558	660.7	598.7	601.8

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دراسة البخر نتح المطلق في منطقة القصيم

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ملخص البحث. تمت دراسة أربع طرق عالمية مختلفة للتنبؤ بالبخر نتح المطلق المنسوب للأعشاب الخضراء، وهي طريقة وعاء البخر القياسي، وطريقة جنسن هيز، وطريقة بنهان المعدلة. وللحصول على قيمة البخر نتح المطلق المنسوب للبرسيم الحجازي نضرب القيم المتحصل عليها من هذه الدراسة في ١,١٧٦٥. وتم عمل برنامج بلغة البيسك وتغذيته ببيانات الأرصاد الجوية لثلاثة مواسم لزراعة القمح وهي (١٩٨٩م)، (١٩٩٠م)، (١٩٩١م) في الفترة من ١٥ ديسمبر إلى ٣٠ إبريل.

كانت كميات البخر نتح المتوسطة منسوبة للأعشاب الخضراء هي ٥٥٨، ٦٦١، ٥٩٩، ٦٠٢مم لطريقة وعاء البخر والأشعة وجنسن هيز وبنهان على الترتيب. وتبين من النتائج المتحصل عليها أن طريقة الأشعة أعطت أرقامًا أعلى لقيم البخر نتح عن الطرق الثلاث الأخرى، ويرجع ذلك إلى أنه تم افتراض قيمة معامل الضبط واحد صحيح. أما إذا تم اختيار قيمة تساوي ٠,٩ فإن قيمة البخر نتح تتساوي تقريبًا مع طريقة جنسن هيز. وتراوحت قيمة معامل وعاء البخر بين ٠,٦ إلى ٠,٦٥ وكان المتوسط الموزون يساوي ٠,٦١ وهذه القيمة منخفضة إذا قارنا قيمة البخر نتح المتحصل عليها بقيم الطرق الأخرى.

أعطت طريقة بنهان قيمًا تتوسط الطرق الأخرى وتم استنتاج قيمة محلية لمعامل الانعكاس للسطح المنزرع بالقمح، وهو ٠,٣٥ وقيمة الأشعة المرتدة بوحدات البخر هي ١,٣٤مم / يوم، وهذه القيم المحلية يمكن استعمالها لتبسيط استخدام معادلة بنهان.

وقد أعطت طريقة جنسن هيز المعايرة محليًا لمنطقة القصيم قيمًا تتوسط الطرق الأخرى، لذلك يمكن القول إن هذه الطريقة مناسبة، فهي عملية، وبسيطة الاستعمال، ولا تحتاج إلى بيانات دقيقة للأرصاد الجوية تكون غالبًا مصدرًا للأخطاء. وقد لا تتوافر أصلاً في بعض المناطق فهي تعتمد أساسًا على درجة الحرارة اليومية المتوسطة.