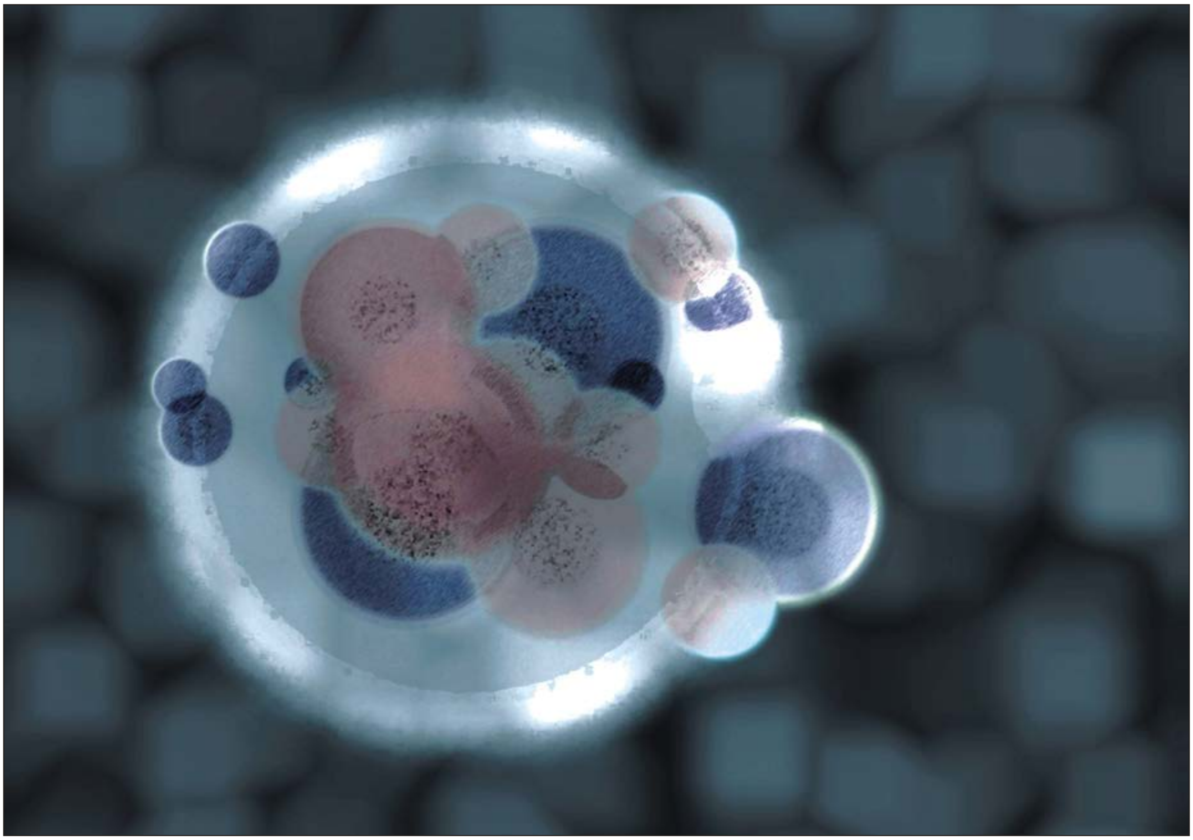

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Performance of Penman-Monteith Alfalafa Reference ET Equation in Selected Site in Kansas, USA

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Abstract: The research has been undertaken to compare the daily reference alfalfa evapotranspiration (ET) value measured by Penman-Monteith method with those determined by the Penman, Adjusted Penman and Jensen methods. Estimation of reference ET has been calculated using 5 years data of Southwest Research Extension Center of Kansas State University (KSU), USA at Garden city kept recorded at KSU Weather Data Library. The comparison of the four methods includes daily peak ET values determined by the methods under study, correlation of the major meteorological data with the ET values, average and total ET values and regression equations with reference to the Penman-Monteith method. The estimation made by the Penman-Monteith method shows the best reflection of the climatic data in comparison to those of the other methods in terms of correlation with climatic parameters.

Key words: Penman-Monteith, Reference evapotranspiration equation, Alfalfa

INTRODUCTION

Evapotranspiration (ET) is one of the important components in studies involving the hydrologic one specifically in the studies related to irrigation planning. ET explains both evaporation and transpiration from soil and vegetative surfaces and is dependent on the atmospheric demand and surface characteristics. The sum of the two terms, that is, transpiration and evaporation is also referred as consumptive use. It has been widely used to predict water requirement of a crop in a field or in a farm or project or a region. A number of ways are being used to predict evapotranspiration, namely direct measurement through field investigations or analytically through energy balance.

Estimation of the actual evapotranspiration of a growing crop involves determining reference (grass or alfalfa) crop evapotranspiration and multiplying with a crop coefficient to adjust for the stage of growth of the crop. ET from a non-limiting vegetative surface has been used as the reference value for predicting crop ET or consumptive use. Jensen *et al*. (1990) termed potential or reference ET as the upper limit of evapotranspiration that occurs from a well watered agricultural crop that has an aerodynamically rough surface, such as alfalfa with 30-50 cm of top growth.

Doorenbos and Prutt *et al*. (1977) defined reference ET as the rate of evapotranspiration from an extensive surface of 8-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

Selection of accurate ET is important for water conservation and improved water management. Water is being utilized for more and more enterprises for the human welfare besides crop production, which calls for judicial application of water. The accurate estimation of ET ensures the better use of water, which is the current global concern to face its ever-increasing scarcity.

The Penman-Montieth (PM) method is based on defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 sm^{-1} and an albedo of 0.23. This closely resembles the evaporation of an extensive surface of green grass of uniform height, that is, actively growing and adequately watered.

The Penman-Montieth (PM) method has provided the best accuracy of ET in arid and humid locations of the world as compared to the performance of various other ET methods, with an overestimation of 4% in the humid and -1% in the arid (Jensen *et al*., 1990). The Penman methods require local calibration of the wind function to achieve satisfactory results.

There are number of approaches or equations for predicting reference ET. For the purpose of establishing uniform evapotranspiration estimates the Technical Committee of the American Society of Civil Engineers

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(ASCE) recommends for two standardized reference evapotranspiration surfaces, (1) a short crop (similar to grass) and (2) a tall crop (similar to alfalfa) and one standardized reference evapotranspiration equation (Walter *et al*., 2000).

The study was undertaken to test the efficiency of Penman Monteith (PM) method for determination of reference evapotranspiration for alfalfa at the Garden city in Kansas and to evaluate the performance of the method in comparison to the other methods being used in the area for predicting reference evapotranspiration.

MATERIALS AND METHODS

The study area is the Southwest Research Extension Center located near Garden City [Lat h^{-1} Long: 37-55-39.056 N/100-43-27.893 W Estimated, Elevation: 2890 ft/880.9 m, surveyed] in Kansas. The climate of the area is semi arid with rainfall less than 18 inches. Corn, grain sorghum, wheat, alfalfa, soybean and sunflower are major crops grown in the area. About 2 million acres in this region depends on Ogallala aquifer, a confined system with extremely limited recharge. The water level is declining and depletion of this non-renewable reserve has become a major focus for the economic sustainability, which calls for judicious use of water resource. ET based irrigation with appropriate soil water monitoring is the most scientific method to implement irrigation scheduling.

Alfalfa reference ET for the 5-years, (1996-2000) has been calculated using FAO-Penman-Monteith equation (PM) for one experimental station of Kansas State University (KSU) located in Kansas, USA. The equation was calibrated for the local conditions in the spreadsheet (Excel) program. The Kansas State University (KSU) Weather data library and South-West research-extension center provided the data and other information. Three methods of alfalfa reference ET calculation are being practiced in the Garden city for irrigation scheduling purpose. These are Penman unadjusted, Penman adjusted and Jensen.

Penman reference evapotranspiration: A spreadsheet template developed by Lamm *et al.* (1987) has been used for the calculation of Penman reference value for alfalfa. The method has been designed for the use in the central United States. The template was implemented in popular spreadsheet products. The climatic data required for the calculation are maximum and minimum temperature (degree Fahrenheit) of last 24 h, the dry-bulb and wet-bulb temperature (degree Fahrenheit) at the 8:00 A.M., observation time, the daily solar radiation (langleys) and the wind run (miles h^{-1} day) recorded daily. This modified Penman method has been adjusted in the local condition considering local cropping pattern (Penman-Adjusted). Adjustment has been made in the wind speed, maximum and minimum temperature. The wind speed more than 270 unit of measurement has been reduced to lower number with the factor of 0. 4586, maximum temperature has been limited to a maximum value of 86 and minimum temperature kept minimum of 50. These have been made considering local crop physiological characteristics. The ET calculated without wind and temperature adjustment is referred as Penman-Unadjusted.

Jensen method: The other method used in the comparison is the Jensen method followed by the Kansas State University (KSU) weather data library, automatic recording station located at experimental field. The method considered maximum and minimum air temperature, maximum and minimum soil temperature, wind run, 8 A. M. relative humidity and solar radiation.

The calculated ET following Penman-Monteith (PM) was compared with locally calibrated Jensen method, Penman (unadjusted) and adjusted Penman methods with reference to alfalfa in the Garden city.

Penman Monteith (PM) equation: The Penman Monteith equation is recommended as the standard method for the definition and estimation of reference evapo-transpiration. The method requires radiation, air temperature, air humidity, wind speed data. It is a physically based model that uses surface and aerodynamic resistances to parameterize water vapor transfer from the canopy into the surrounding atmosphere. The surface resistance of the model is

$$\eta ET = \frac{\Delta(R_n - G) + K_{timepa} C_p (e_s - e_a)/r_a}{\Delta + \lambda(1 + r_s/r_a)}$$

Where:

R_n = Net radiation at crop surface in MJ m^{-2} day^{-1};
G = Soil heat flux density (considered as zero for daily values), MJ m^{-2} day^{-1};
T = Mean daily air temperature at 2 m height;
e_s-e_a = Vapor pressure deficit of the air, kPa;
e_s = Saturation vapor pressure of the air, kPa;
e_a = Actual vapor pressure of the air kPa;
ρ_a = Mean air density at constant pressure, kg m^{-3};
$°C_p$ = Specific heat of the air, MJ kg^{-1} $°C^{-1}$;
Δ = Slope of the saturation vapor pressure temperature relationship, kPa$°C^{-1}$;
γ = Psychrometric constant, kPa$°C^{-1}$;
r_s = Surface resistance [100 h^{-1} (0.5 LAI)] sm^{-1};
r_a = Aerodynamic resistance sm^{-1};

H = Latent heat of vaporization Mj kg^{-1};
K_{time} = A unit conversion (86400 sd^{-1} for mm day^{-1} and 3600 sh^{-1} in mm h^{-1};
η = Latent heat of vaporization, 2.45.

LAI has been calculated with the equation, LAI = 1.5 ln (h_c)-1.4, h_c in cm for alfalfa (Jensen *et al*., 1990).

Aerodynamic resistance is referred to as:

$$r_a = \frac{\ln[(z_m - d)/z_{om}]\ln[(z_h - d)/z_{oh}]}{KU_z}$$

Where:

Z_m = ht of the wind measurement, meter,
Z_h = ht of the humidity measurement,
d = Zero plane displacement ht, m,
Z_{om} = Roughness length governing momentum transfer, m,
Z_{oh} = Roughness length governing transfer of heat and vapor;
K = Von Kerman's constant-0.41,
U_z = Wind speed at height z, ms^{-1}.

For calculation of r_a

Z_m = 3.04 m, d = 2 h^{-1} 3 h_c, (h_c = crop ht. 0.5 m for alfalfa)
Z_{om} = 0.0615 m, Z_{oh} = 0.1(Z_{om}), = 0.00615 m
r_a = 126/U_2

The stomatal resistance of a single leaf has a value of about 100 sm^{-1}, which estimates r_s value comes as 45 sm^{-1}. Considering alfalfa crop with height, 0.5 m, the anemometer height of 10 feet (3.04 m) and all other instrument height as 2 m.

After reorganization (albedo, 0.23, Stefan-Boltzman constant, 4.903 10^{-9} MJK^{-4} m^{-2} day^{-1}, R = specific gas constant = 0.287 KJ kg^{-1} K^{-1}, ε = ratio of molecular weight of water vapor, 0.622) and using the expression the Penman-Monteith equation becomes:

$$ET = \frac{0.408\Delta(R_n - G) + \gamma[1472/(T+273)]U_2(e_s - e_a)}{\Delta + \lambda(1+.4U_2)}$$

Walter *et al*. (2000) evaluated constants of the PM equations and found 1600 and 0.38 respectively in place of the 1472 and 0.4 (ht. of the anemometer as 2.0 m and air temp and humidity measurement as 1.5-2.5 m) in the above equation for estimating daily falfa reference with an approximate height of 0.5 m. Allen *et al*. (1989), based on data analysis found coefficients as 1700 and 0.40 for alfalfa.

Clear sky solar radiation (R_{so}) and coefficients for computing net longwave radiation has been calculated following the method described in FAO-56 (Eq. 37 to 39, Allen *et al*., 1998).

RESULTS AND DISCUSSION

Correlation: Correlation analysis has been made with ET derived from the Penman Monteith, Penman Unadjusted, Penman-Adjusted and Jensen methods and the climatic parameters of Garden city (Table 1) during the growing perdiod (April-September). It has been found that ET derived from PM has high correlation with the parameters like temperature, solar radiation and relative humidity. This ranges from 0.39 to 0.71 for temperature, 0.62 to 0.77 for solar radiation and 0.61 to 0.76 for relative humidity. ET derived from both PM and Penman-Unadjusted shows higher correlation with wind speed than that found from Penman adjusted and Jensen method. Penman adjusted method represents weak relation with wind speed and it ranges from 0.038 in, 1996 to 0.33 in, 1998. On the other hand, ET derived through Jensen method shows inverse association with relative humidity.

Peak reference ET: The peak reference ET ranges from 12.6 to 24.4 mm day^{-1} in PM method while for unadjusted Penman, it varies from 13.15 to 27.1 mm day^{-1}. For adjusted Penman it ranges from 11.1 to 15.7 mm day^{-1} and 15.2 to 29.2 mm day^{-1} for Jensen method for 5 years. In

Table 1: Correlation matrix of different methods of reference ET with major climatic features in Garden city

Parameters	PM	Penm-Unadj	Pen-Adjst	Jensen
1996				
Temperature	0.392	0.322	0.475	0.679
Wind	0.275	0.386	0.038	0.105
Solar Rad	0.713	0.662	0.776	0.790
RH	-0.760	-0.720	-0.643	-0.356
1997				
Temperature	0.602	0.613	0.673	0.759
Wind	0.296	0.332	0.117	0.169
Solar Rad	0.776	0.800	0.818	0.828
RH	-0.752	-0.721	-0.674	-0.392
1998				
Temperature	0.580	0.523	0.655	0.711
Wind	0.505	0.582	0.335	0.389
Solar Rad	0.662	0.644	0.761	0.495
RH	-0.739	-0.713	-0.802	-0.490
1999				
Temperature	0.711	0.692	0.736	0.770
Wind	0.373	0.427	0.170	0.316
Solar Rad	0.768	0.774	0.843	0.812
RH	-0.706	-0.690	-0.703	-0.568
2000				
Temperature	0.548	0.513	0.636	0.676
Wind	0.481	0.503	0.181	0.350
Solar Rad	0.624	0.645	0.717	0.749
RH	-0.608	-0.646	-0.655	-0.448

PM: Penman-Monteith; Undj: Unadjusted Penman, Pen: Penman method

Table 2: Peak ET (mm day^{-1}) by different methods in the Garden city during 1996-2000

Methods	Date (month/day)	p-value	Corresponding weather data	Corresponding ET values
1996				
PM	5/18	17.5	Tmax:104, Sol: 601,Wind: 340 RH: 36	Unadjst-16.47, Adjst.-10.7 and Jensen-13.7
Unadjst	4/2	19.3	Tmax: 88, Sol: 543, Wind: 420, RH:15.3	PM, 16.47 and Adjst.-10.7
Adjst	5/17	14.7	Tmax: 99, Wind: 250, Sol 686, RH:26.8	PM-14.6 and Unadjst.-14.7
Jensen	6/21	18.3	Tmax: 98, Wind: 278, Sol 661, RH:57	PM- 2.2, Unadjst.-12.9 and adjst.-9.26
1997				
PM	7/1	14.5	Tmax: 103, Sol: 777, Wind: 235, RH:37	Unadjst-13.6, Adjst.-13.6 and Jensen-15.2
Unadjst	6/20	13.15	Tmax: 101, Sol: 670, Wind: 256, RH:39	PM-14.0 and Adjst.-13.15 and Jensen-14.36
Adjst	7/1	13.6	Tmax: 103, Sol: 777, Wind: 235, RH:37	PM-14.5, Unadjst. 13.6 and Jensen-15.2
Jensen	7/1	15.2	Tmax: 103, Wind: 235, Sol 777, RH:37.3	PM-14.5, Unadjst. 13.6, and adjst-13.6
1998				
PM	6/24	24.4	Tmax: 102, Sol: 593, Wind: 715, RH:32	Unadjst- 27.1 Adjst. 15.55 and Jensen-25.75
Unadjst	6/24	27.1	Tmax: 102, Sol: 593, Wind: 715, RH:32	PM, 24.4, Adjst. 15.55 and Jensen-25.75
Adjst	6/17	15.7	Tmax: 100, Sol: 775, Wind: 826, RH:41	PM, 23.9, Unadjst. 26.3, Jensen-24.68
Jensen	9/25	29.2	Tmax: 99, Sol: 530, Wind: 439, RH:57	PM- 14.34, Unadjst. 11.8 and Adjst:7.78
1999				
PM	8/31	12.6	Tmax: 95, Sol: 592, Wind: 341, RH:51	Unadjst- 11.9, Adjst. 8.5 and Jensen-14.4
Unadjst	7/4	13.5	Tmax: 92, Sol: 723, Wind: 451, RH:61.6	PM, 12.6, Adjst. 9.7 and Jensen 17.1
Adjst	7/25	11.1	Tmax: 101, Sol: 696, Wind: 257, RH:56	PM-12.5, Unadjst. 11.1 and Jensen-13
Jensen	7/4	17.1	Tmax:92, Sol: 723, Wind: 450, RH: 61.6	PM-12.6, Unadjst.-13.5, Adjst-9.7
2000				
PM	5/29	17.1	Tmax: 100, Sol: 724, Wind: 374, RH:40	Unadjst, 17.2, Adjst. 11.4 and Jensen- 15.6
Unadjst	5/29	17.2	Tmax: 100, Sol: 724, Wind: 374, RH:40	PM, 12.7 and Adjst. 11.9, Jensen, 15.6
Adjst	8/15	12.6	Tmax: 100.5, Sol: 581, Wind: 244, RH:38	PM, 13.1 mm and Unadjst. 12.6 mm
Jensen	7/9	16.2	Tmax: 101, Wind: 308, Sol 746, RH:46	PM, 15.0 and Unadjst. 14.9, adjst: 10.72

Values of Solar Radiation (Sol) is in Langley per day, Tmax in °F, Wind speed in miles per day, Relative Humidity (RH) in %

1996, Penman-Monteith shows the peak ET on 5 h^{-1} 18 as 17.5 mm day^{-1} against the T max value of 104 °F (highest maximum temperature of the season), solar radiation of 601 Langley, wind of 340 miles per day and RH of 36% while unadjusted Penman, Adjusted Penman and Jensen methods estimated to be 16.47, 10.7 and 13.77 mm respectively for the same day (Table 2). In 1997, Penman-Monteith, Adjusted Penman and Jensen methods reached peak reference ET value on the same day (July 1) as 14.5, 13.6 and 15.2 mm day^{-1} respectively against both highest solar radiation (777 Langley per day) and maximum peak reference ET value on the same day (July 1) as 14.5, peak reference ET value on the same day (July 1) as 14.5, 13.6 and 15.2 mm day^{-1}, respectively against both highest solar radiation (777 Langley per day) and maximum temperature (103 °F) value in the season. The peak ET values usually represented the high values of climatic parameters.

The daily ET values in the growing season (April-September) by the methods were compared. The Jensen method estimates negative values of ET corresponding to the lower climatic values. The Jensen method usually overestimates the daily reference ET in most of the years studied except few days in the early part of the season.

Regression: The coefficient of determination and regression analysis of Penman Monteith equation with other methods show the linear relationship with Penman-

Table 3: Regression of daily alfalfa reference evapotranspiration (mm), estimated by three methods with reference to Penman-Monteith equation for 1996-2000

Years	Regression equation			Coefficient of determination (R^2)
1996	$Et_{unadjusted}$	=	$0.5266+0.9793\ (ET_{PM})$	0.9140
	$ET_{Adjusted}$	=	$1.342(ET_{PM})0.8249$	0.8553
	ET_{Jensen}	=	$1.6991(ET_{PM})^{0.7827}$	0.7339
1997	$Et_{unadjusted}$	=	$0.2703+0.8829(ET_{PM})$	0.9631
	$ET_{Adjusted}$	=	$1.051(ET_{PM})^{0.9002}$	0.9505
	ET_{Jensen}	=	$1.036+0.9352(ET_{PM})$	0.6971
1998	$Et_{unadjusted}$	=	$0.9712(ET_{PM})-0.273$	0.9405
	$ET_{Adjusted}$	=	$1.1201(ET_{PM})^{0.844}$	0.9241
	ET_{Jensen}	=	$1.7021(ET_{PM})^{0.8545}$	0.7184
1999	$Et_{unadjusted}$	=	$0.0162+0.9287(ET_{PM})$	0.9684
	$ET_{Adjusted}$	=	$0.9504(ET_{PM})^{0.9455}$	0.9300
	ET_{Jensen}	=	$0.0011+1.1002(ET_{PM})$	0.8957
2000	$Et_{unadjusted}$	=	$1.0014\ (ET_{PM})-0.1361$	0.9699
	$ET_{Adjusted}$	=	$1.0332(ET_{PM})^{0.9238}$	0.8671
	ET_{Jensen}	=	$0.1369+9114(ET_{PM})$	0.8399

Analysis of variance indicates that the total growing period reference ET by PM during the five years differs significantly with the Penman (Adjusted) and Jensen method at 5% level of significance. But there seems no significant difference between the ET calculated by Penman-Monteith and Penman unadjusted method at5% level of significance

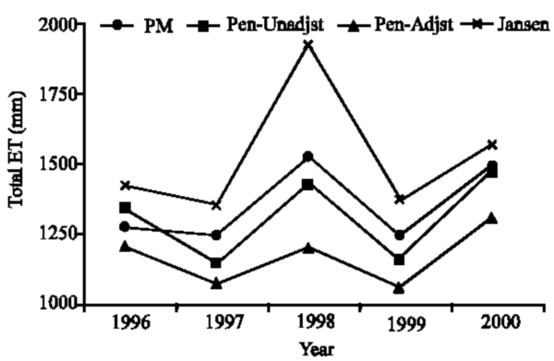

Fig. 1: Total ET for the growing period (yearly average of April-September

Unadjusted equation and power relationship with Penman Adjusted equation throughout the years, (1996-2000) (Table 3). The coefficient of determination (R^{-2}) has been calculated to be more than 0.90 during the study years while comparing with unadjusted Penman method. Coefficient of determination is found to vary from 0.85-0.95 with adjusted Penman method. The coefficient of determination for Jensen is less than 0.70 in, 1996 and regression equations are found to vary between linear and power function.

The Fig. 1 shows the total growing period ET as found for the five years derived by the four methods. It indicates that the Jensen method overestimates the ET in most of the years. The value determined by the Adjusted Penman method appears to be the lowest. The total ET found from both PM and unadjusted Penman remains fairly parallel and close to each other. Figure 1 shows the average climatic data during the growing periods (Solar radiation, wind speed and Temperature) which indicates the higher climatic values in the year, 1998 and 2000 reflecting total ET curves during the same period.

The Jensen method estimates negative values of reference ET during September 23 and 24 in the year, 2000 in response to the lower values of solar radiation and wind speed (lower than 140 langley and around 200 miles per day for solar radiation and wind speed respectively). In, 1997, reference ET shows negative value in April 10 against the mean temperature, solar radiation and wind speed value of 36.5 °F, 89.8 langley and 214 miles per day respectively. Similarly, April 29 in, 1998 yields negative reference ET value of 0.5 mm against abnormally low solar radiation data of 15.5 langley. In, 1999 September 28 comes with negative value of 0.19 mm corresponding to the mean temperature, solar radiation and wind speed value of 50.1°F, 109.8 langley and 195 miles per day, respectively.

CONCLUSIONS

The estimation of alfalfa reference evapotranspiration by the Penman-Monteith equation shows better reflection of climatic data than other methods in terms of correlation with climatic parameters at the site. Coefficient of determinations found from PM method show higher values than those derived by Penman Adjusted and Unadjusted methods in Garden city. Jensen method overestimates the daily reference ET as well as produces negative values corresponding to the lower climatic parameters. The PM neither over estimates nor under estimates the alfalfa reference ET in Garden city. As alfalfa reference ET estimated by PM and unadjusted Penman shows no significant difference, PM method appears more convenient requiring no climatic data adjustment. So the PM method may fairly be used for calculating ET values in Garden city.

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