International Journal of Agriculture Sciences
ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 13, Issue 4, 2021, pp.-10731-10734.
Available online at https://bioinfopublication.org/pages/jouarchive.php?id=BPJ0000217

Research Article

REFERENCE EVAPO-TRANSPIRATION (ETo): BLANEY-CRIDDLE AND JENSEN-HAISE METHODS FOR BLACKGRAM AND WHEAT CROPS

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Received: April 03, 2021; Revised: April 26, 2021; Accepted: April 27, 2021; Published: April 30, 2021

Abstract: CERES wheat and CROPGRO model (DSSAT version v4.5) were used in this study for assessment of ETo. Blackgram season accumulated ETo mm during the years 2007 and 2008 for simulated, Jenson-Haise method and Blaney-Criddle method were 39.04 and 38.39, 37.66 and 39.19 and 40.83 and 36.56 respectively. Wheat season accumulated reference evapotranspiration for 2007 and 2008 for simulated, Jenson-Haise method and Blaney-Criddle method were 40.83 and 41.76, 35.61 and 39.64, 40.82 and 46.08 respectively. Overall, the calibrated ETo by Jensen-Haise method gave closer percentage over simulated ETo with higher correlation and lower error percentage as compare with Blaney-Criddle method. The results revealed that the CERES wheat and CROPGRO model satisfactorily simulated the ETo mm/day.

Keywords: *CERES model, CROPGRO model, Reference evapotranspiration (ETo), Emprical methods, Wheat, Blackgram*

Citation: Neeraj Kumar, *et al*., (2021) Reference Evapo-transpiration (ETo): Blaney-Criddle and Jensen-Haise Methods for Blackgram and Wheat Crops. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 13, Issue 4, pp.- 10731-10734.

Introduction

Evapotranspiration is the sum of the volume of water used by vegetation (transpiration) and that evaporated from the soil and intercepted precipitation. The reference evapotranspiration (ETo) concept was introduced by irrigation engineers and researchers in the late 1970s and early 80s [1] to avoid ambiguities that existed in the definition of potential evapotranspiration by adopting a reference crop, it has become easier and more practical to select consistent crop coefficients and to make reliable actual crop evapotranspiration (ET) estimates in new areas. Introduction of the reference evapotranspiration concept also helped to enhance the transferability of the crop coefficients from one location to another. In addition, with using reference evapotranspiration, it is easier to select consistent crop coefficients and to calibrate evapotranspiration equations for a given local climate [2]. But selection of the appropriate evapotranspiration model for a specific situation is difficult. It estimates varyingly with various methods and unfortunately no definite guidelines are available for defining the model or method of application most likely to give the best estimate [3]. The Decision Support System for Agro technology Transfer (DSSAT) has been in use for more than 15 years in over 100 countries worldwide [4]. Through these crop models, it became possible to simulate a living plant through the mathematical and conceptual relationship which governs its growth in the soil atmospheric continuum [5]. Crop weather model may also be defined as a simplification of the complex relationship between weather on one hand and crop performance on the other by using mathematical and statistical techniques. Crop models can help researchers, policymakers, and farmers to make correct decisions on crop management practices, and also for marketing strategies and food security of a country with a deterministic view on the import-export market [6].

Materials and Methods

Pant Nagar is situated at Shivalic range of Himalayas at 29°1'N, latitude, 79.28°E longitude and at an altitude of 215.00 m above the mean sea level. The climate of Pant Nagar is temperate with severe cold winter and hot summer. The CERES-Wheat model was used for simulation of daily phenological development and growth in response to environmental factors (soils, weather and management). CROPGRO version v4.5 was used for Blackgram in this study. The data base included all relevant information including the different management practices adopted, location specific soil and weather conditions obtained from field experiment conducted during kharif and rabi seasons of 2007 and 2008 at Crop Research Center, GBPUAT Pant Nagar, Uttarakhand. In this study, replicated data were used in the model calibration and validation process. Blackgram (Vigna mungo L. Hepper) Pant Blackgram- 31 variety and Wheat (*Triticum aestivum* L.) UP-2565 was used in this study. The Blackgram crop was fertilized at the rate of 20:40:20 of N: P_2O_5: K_2O of which one third nitrogen and full dose of phosphorus and potash were applied homogeneously as basal dressing and remaining dose of nitrogen were top dressed at 21 days interval. Similarly, wheat crop was fertilized at the rate of 100 and 150 kg ha^{-1} N levels, 60 kg ha^{-1} P_2O_5, 40 kg ha^{-1} K_2O of which one third of nitrogen and whole phosphorus and potash were applied uniformly as basal dressing and incorporated in surface soil. Remaining doses of nitrogen levels was top dressed in two equal splits at crown root initiation (CRI) and vegetative stage of wheat crop.

The following equations were given by Jensen - Haise and Blaney - Criddle for the estimation of ETo.

Blaney -Criddle method (1950) [7]

$$ETo = p \cdot (0.46 \cdot T_{mean} + 8)$$

Where:

ETo is the reference evapotranspiration [mm day−1]

T_{mean} is the mean daily temperature [°C] given as $T_{mean} = (T_{max} + T_{min})/2$

p is the mean daily percentage of annual daytime hours.

Table-1 *Comparison of measured and calculated values of reference evapotranspiration (ETo mm/day) for Blackgram*

SN	Std week	Week	2007					Std week	Week	2008				
			ET			% of simulated				ET			% of simulated	
			S	JH ET	BC ET	JH ET	BC ET			S	JH ET	BC ET	JH ET	BC ET
1.	29	16-22 July	3.21	3.31	3.9	103.12	121.50	32	06-12 Aug.	3.07	3.85	3.3	125.41	107.49
2.	30	23-29July.	2.46	2.6	2.41	105.69	97.97	33	13-19 Aug.	2.48	2.31	1.83	93.15	73.79
3.	31	30July-05 Aug.	3.24	3.21	3.23	99.07	99.69	34	20 -26 Aug.	4.7	3.41	3.93	72.55	83.62
4.	32	06-12 Aug.	3.77	3.18	3.76	84.35	99.73	35	27Aug-02 Sep.	3.4	3.41	3.38	100.29	99.41
5.	33	13-19 Aug.	2.82	3.07	3.36	108.87	119.15	36	03-09 Sep.	3.5	4.23	3.37	120.86	96.29
6.	34	20 -26 Aug.	3.37	2.91	3.63	86.35	107.72	37	10-16 Sep.	2.91	3.80	3.88	130.58	133.33
7.	35	27Aug-02 Sep.	3.95	2.89	3.42	73.16	86.58	38	17-23 Sep.	3.45	2.56	3.33	74.20	96.52
8.	36	03-09 Sep.	3.55	3.22	3.06	90.70	86.20	39	24-30 Sep.	2.39	2.57	2.25	107.53	94.14
9.	37	10-16 Sep.	2.4	3.13	2.04	130.42	85.00	40	01-07Oct.	2.32	3.03	2.25	130.60	96.98
10.	38	17-23 Sep.	3.3	3.11	3.18	94.24	96.36	41	08-14 Oct.	3.39	3.57	3.44	105.31	101.47
11.	39	24-30 Sep.	2.22	2.44	2.71	109.91	122.07	42	14-21 Oct.	3.63	3.29	3.04	90.63	83.75
12.	40	01-07Oct.	2.54	2.58	2.57	101.57	101.18	43	21-28 Oct	3.15	3.16	2.56	100.32	81.27
13.	41	08-14 Oct.	2.21	2.01	3.56	90.95	161.09	-	-	-	-	-	-	-
Total			39.04	37.66	40.83			Total		38.39	39.19	36.56		
Average			3.00	2.90	3.14			Average		3.20	3.27	3.05		
CV%			19.83	13.25	17.86			CV%		20.47	17.65	22.08		

Table-2 *Comparison of Measured with Calculated values of reference evapotranspiration (ETo mm/day) for wheat*

SN	Std week	Week	2007					Std week	Week	2008				
			ET			% of simulated				ET			% of simulated	
			S	JH ET	BC ET	JH ET	BC ET			S	JH ET	BC ET	JH ET	BC ET
1.	49	03-09 Dec.	1.65	1.08	1.71	65.45	103.64	48	27Nov.-03Dec	1.82	1.44	1.60	79.12	87.91
2.	50	10-16 Dec.	1.91	1.34	1.17	70.16	61.26	49	03-09 Dec.	1.91	1.60	1.56	83.77	81.68
3.	51	17-23Dec.	1.83	1.07	1.68	58.47	91.80	50	10-16 Dec.	1.44	1.05	1.66	72.92	115.28
4.	52	24-31 Dec.	1.34	0.96	1.66	71.64	123.88	51	17-23Dec.	0.75	0.5	0.67	66.67	89.33
5.	1	01-07 Jan.	1.11	1.03	1.16	92.79	104.50	52	24-31 Dec.	1	0.38	1.10	38.00	110.00
6.	2	08-14 Jan.	1.09	1.13	1.86	103.67	170.64	1	01-07 Jan.	2.4	2.43	2.46	101.25	102.50
7.	3	15-21 Jan.	0.91	0.62	0.89	68.13	97.80	2	08-14 Jan.	1.02	1.56	1.37	152.94	134.31
8.	4	22-28 Jan.	1.91	0.87	1.66	45.55	86.91	3	15-21 Jan.	3.12	2.54	2.14	81.41	68.59
9.	5	29Jan.-04Feb.	1.6	1.18	2.98	73.75	186.25	4	22-28 Jan.	1.14	1.75	2.75	153.51	241.23
10.	6	05-11 Feb.	1.85	1.11	1.98	60.00	107.03	5	29Jan.-04Feb.	1.9	0.76	1.50	40.00	78.95
11.	7	12-18 Feb.	2.54	2.57	2.55	101.18	100.39	6	05-11 Feb.	1.07	1.08	3.36	100.93	314.02
12.	8	19-25Feb.	2.1	1.93	1.18	91.90	56.19	7	12-18 Feb.	2.26	1.41	2.86	62.39	126.55
13.	9	26Feb.-04 Mar.	2.17	1.36	1.28	62.67	58.99	8	19-25Feb.	3.35	3.15	3.47	94.03	103.58
14.	10	05-11 Mar.	3.58	3.94	3.51	110.06	98.04	9	26Feb.-04 Mar.	3.15	3.23	3.41	102.54	108.25
15.	11	12-18Mar.	2.42	2.48	2.08	102.48	85.95	10	05-11 Mar.	3.64	3.32	3.84	91.21	105.49
16.	12	19-25 mar.	3.28	3.28	3.25	100.00	99.09	11	12-18Mar.	2.74	3.34	2.98	121.90	108.76
17.	13	26mar.-01Apr.	3.11	3.09	3.46	99.36	111.25	12	19-25 mar.	2.5	2.57	2.40	102.80	96.00
18.	14	02-08Apr.	2.25	3.26	3.21	144.89	142.67	13	26mar.-01Apr.	3.26	3.78	3.84	115.95	117.79
19.	15	09-15Apr.	3.78	3.31	3.55	87.57	93.92	14	02-08Apr.	3.29	3.75	3.11	113.98	94.53
Total			40.43	35.61	40.82			Total		41.76	39.64	46.08		
Average			2.13	1.87	2.15			Average		2.26	2.13	2.46		
CV%			38.99	56.43	42.41			CV%		43.05	53.59	39.97		

S-Simulated, JH-Jensen Haise, BC-Blaney Criddle

Jensen-Haise Method (1963): The Jensen-Haise equation (cal/cm^2/d) represents a temperature-radiation method of calculating a daily ETr [8]. The Jensen-Haise equation is as follows:

ETo= CT (T_{mean}-Tx) Rs

where:

CT is the temperature coefficient.

T_{mean} is the daily mean temperature in EF.

Tx is the intercept of the temperature axis as calculated for weather station.

Rs is the measured global solar radiation in cal/cm^2/day

The product of CT (T_{mean}-Tx) represents a weighting function on Rs.

The summary measures describe the quality of simulation while the difference measures try to locate and quantify errors. The latter include the mean absolute error (MAE), the mean bias error (MBE) and the root mean square error (RMSE) [9].

$$\text{MAE} = \sum_{i=1}^{n}\left[|S_i - C_i|\right]/n$$

$$\text{MBE} = \sum_{i=1}^{n}\left[S_i - C_i\right]/n$$

$$\text{RMSE} = \left[\sum_{i=1}^{n}(S_i - C_i)^2/n\right]^{1/2}$$

MAE and RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between simulated (S) and calculated (C). The statistic MBE describes the direction of the error bias. The value of MBE is related to the magnitude of the values under investigation. A negative MBE indicates that the forecasting is smaller in values than those of the corresponding observations. PE is defined as ratio of RMSE to mean observed value expressed as percentage [9].

$$\text{PE} = \frac{\text{RMSE}}{\overline{O}} \times 100$$

Results and Discussion

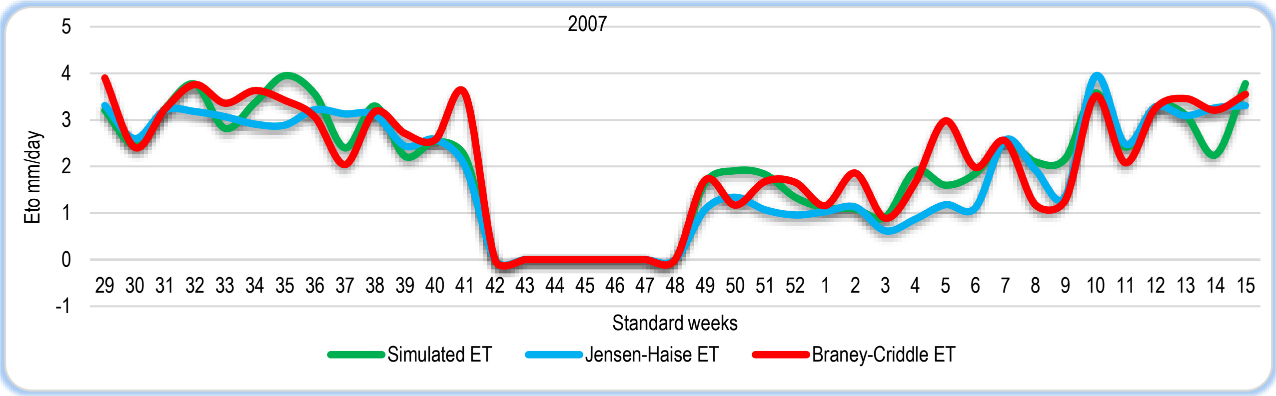
Comparison between simulated and calculated ETo for Blackgram

It is revealed form the data the simulated, Jenson-Haise method and Blaney-Criddle method ETo mm/day for 2007 and 2008 were ranged between 2.21 to 3.95 and 2.32 to 4.7, 2.01 to 3.31 and 2.56 to 4.23, 2.04 to 3.76 and 1.83 to 3.93 respectively [Table-1] and [Fig-1]. During 2008 all the methods reported higher ETo as compare with 2007 data, which means during 2008 crop loosed more water, this is may be due to higher temperature during the maturity stage.

Table-3 *Error analysis between simulated and calculated ETo for Blackgram and wheat crops*

Error structure	Blackgram				Wheat			
	2007		2008		2007		2008	
	JH ETo	BC ETo	JH ETo	BC ETo	JH ETo	BC ETo	JH ETo	BC ETo
MAE	0.33	0.38	0.52	0.36	0.41	0.40	0.43	0.46
MBE	-0.11	0.14	0.07	-0.15	-0.25	0.02	-0.13	0.20
RMSE	0.44	0.52	0.65	0.48	0.53	0.57	0.51	0.72
PE %	14.73	17.44	20.38	15.00	24.89	26.66	22.40	31.68
Correl. Co.	0.66	0.59	0.40	0.74	0.90	0.78	0.89	0.73

S-Simulated, JH-Jensen Haise, BC-Blaney Criddle



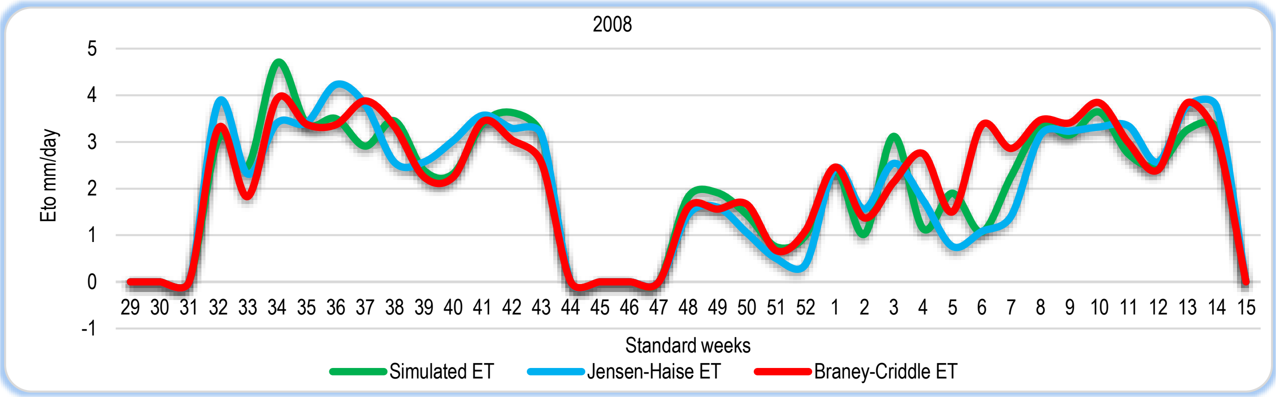


Fig-1-2 Comparison of simulated, Jensen-Haise and Braney-Criddle method of ETo for black gram and wheat (mm day-1) during 2007 and 2008

The overall analysis indicated that Jenson-Haise method calculations were close to simulated reference evapotranspiration for both the years. Crop season accumulated ETo mm during the years 2007 and 2008 for simulated, Jenson-Haise method and Blaney-Criddle method were 39.04 and 38.39, 37.66 and 39.19 and 40.83 and 36.56 respectively. Jensen-Haise method during 2007 gave the MAE, MBE, RMSE and percent error were 0.33, -0.11, 0.44 and 14.73 mm/day respectively with coefficients of correlation 0.66 with R^2=0.36 and during 2008 MAE, MBE, RMSE and percent error were 0.52, 0.07, 0.65 and 20.38 mm/day respectively with coefficients of correlation 0.40 and R^2=0.01. While Blaney-Criddle method during 2007 gave the MAE, MBE, RMSE and percent error were 0.38, 0.14, 0.52 and 17.44 mm/day respectively with coefficients of correlation 0.59 and R^2=0.17, while during 2008 MAE, MBE, RMSE and percent error were 0.36, -0.15, 0.48 and 15.00 mm/day respectively with coefficients of correlation 0.74 and R^2=0.46 [Table-3]. Overall, the calibrated ETo by Jensen-Haise method gave closer percentage of simulated ETo with higher correlation and lower error percentage. Findings of [10] found that seasonal pattern of soil water stress coefficients showed that water losses was faster at grain filling stage than at other stages.

Comparison between simulated and calculated ETo for wheat

The ETo mm/day data on simulated, Jenson-Haise method and Blaney-Criddle method for 2007 and 2008 were ranged between 1.09 to 3.7 and 0.75 to 3.64, 0.62 to 3.94 and 0.5 to 3.78, 0.89 to 3.55 respectively [Table-2] and [Fig-2]. Blaney-Criddle method calculations were over predicted in both years as compare with simulated data base, while Henson-Haise method gave under predictions. Overall analysis showed that the Jenson-Haise method calculations for ETo were close to simulated values. Crop season accumulated reference evapotranspiration for 2007 and 2008 for simulated, Jenson-Haise method and Blaney-Criddle method were 40.83 and 41.76, 35.61 and 39.64, 40.82 and 46.08 respectively. Jensen-Haise method during 2007 gave the MAE, MBE, RMSE and percent error were 0.41, -0.25, 0.53 and 24.89 mm/day respectively with coefficients of correlation 0.90 and R^2=0.58, while during 2008 MAE, MBE, RMSE and percent error were 0.43, -0.13, 0.51 and 22.40 mm/day respectively with coefficients of correlation 0.89 and R^2=0.50. Blaney-Criddle method during 2007 gave the MAE, MBE, RMSE and percent error were 0.40, 0.02, 0.57 and 26.66 mm/day respectively with coefficients of correlation 0.78 and R^2=0.58, similarly during 2008 MAE, MBE, RMSE and percent error were 0.46, -0.20, 0.72 and 31.68 mm/day respectively with coefficients of correlation 0.73 and R^2=0.50 [Table-3]. Similar type of comparison of methods for estimating reference evapotranspiration was given by [11].

Conclusion

This study presented different approaches for estimating reference evapotranspiration for blackgram and wheat crops through simulation modeling and empirical methods. The study indicated that the DSSAT model with empirical methods may be useful tool for calculating ETo.

Reference evapotranspiration is helpful for calibration of reference evapotranspiration equations for local climate, irrigation scheduling, water management, hydrologic studies and drainage researches for Uttarakhand region.

Application of research: Reference evapo-transpiration of blackgram and wheat crop

Research Category: Agro-meteorology

Abbreviations: ET-Evapotransoiration, RMSE-Root mean square, S- Simulated, JH-Jensen Haise, BC-Blaney Criddle

Acknowledgement / Funding: The authors are thankful to Department of Agrometeorology, G.B. Pant University of Agricultural and Technology, Pantnagar, Uttarakhand for guidance and support for carrying out research. The authors are also thankful to University Grants Commission (UGC) towards providing financial assistance to carry out research.

****Principal Investigator or Chairperson of research: Dr. Neeraj Kumar**
University: G.B. Pant University of Agricultural and Technology, Pantnagar
Research project name or number: PhD Research

Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Pantnagar (UK)

Cultivar / Variety / Breed name: Pant Blackgram- 31 and Wheat UP-2565

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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