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Study Of Reference Evapotranspiration Based Deficit Irrigation In The Sone Command Area In Bihar, India – A Case Study

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ABSTRACT

Deficit irrigation is a method of applying water to the field in such a manner that it maximizes the water use efficiency, so as to get higher yield per unit of irrigation water applied to the field. In the present study evapotranspiration based deficit irrigation has been analyzed for the Sone command area. For estimating reference evapotranspiration and for the crop water requirement, CROPWAT 8.0 decision support tool is used. For the present study the climatological data is obtained during the 1999-2015 in ICAR farm, Patna. The impact of deficit irrigation, yield response to water stress was evaluated by using four crop water production functions. The aim of the present study is to analyze the potential and suitability of the models in forecasting yield response of maize and wheat crops. The assessments of four crop-production functions were Jensen, Minhas et al., Stewart et al., and Rao et al. models. For maize crop, the percentage reduction in yield with ten percent in ET_c by Jensen, Minhas et al., Stewart et al. and Rao et al. is 29, 3.16, 32 and 28.2 respectively. For wheat crop, the percent reduction in yield is 12.16, 1.2, 15, 14.4 respectively. By comparing these models by 10, 20, 30, 40 and 50 percent in crop evapotranspiration (ET_c), the steward et al. model gives the over predicted yield values and Minhas et al. model gives the under predicted yield values. Therefore, the performance of Jensen and Rao et al. were considered better as compared to stewart et al. and Minhas et al. models to monitor crop yield response to deficit in availability of water.

Keywords: Deficit irrigation, Reference Evapotranspiration, Crop Water requirement, yield response to crops.

1. INTRODUCTION

Water shortage for all kind of demands in human life has become a major threat; the only feasible solution to make effective and efficient use of irrigation water for agriculture as well as our day-to-day life. Sustainable use of water resources can help us to overcome this threat. The irrigation water is deficient, by applying proper scheduling can increase the crop yield. Deficit in availability of water for crop is going to be very common in near future, this deficit of water taking place at a particular stage of crop growth may cause yield reduction compared to the same deficit at other growth stages (Hansen, S. 1984, Hargreaves et al., 1994, Panda et al., 2003, Fereres et al., 2006, Upchurch et al., 2015).
Due to non uniformity in the response of crop growth to water deficits, it is necessary to distribute deficits among different stages for a crop.

For proper growth of the crop a specific amount of water is required this requirement is also known as crop water requirement, crop draws water from soil through its root system, provided sufficient amount of water is available on the soil reservoir. When this soil reservoir starts depleting, the crop continues to draw water as per its requirement. For some stage of depletion level, the crop can draw water to meet total requirements but after some depletion level, though the crop still needs water, the water available is less which gives rise to stress or deficit condition (Rao et al., 1987, Chattopadhyay et al. 1996, Paul et al., 2000, Roy et al. 2001, Taghvaeian et al. 2012).Crop evapotranspiration (ET_c) is the evapotranspiration of the crop taking place in ideal conditions when soil- water is in optimum condition. But when the water available is scarce or water supply to the crop is limited crop water requirements are not met with actual evapotranspiration. Consequently, a decrease in the seasonal yield is observed. This decrease in the seasonal yield is calculated by using Doorenbos and Kasaam (1979) model which gives relationship between reductions taking place in the yield of crop with the occurring water deficit.

CROPWAT Model 8.0 has been used to calculate the crop water requirements and irrigation requirements depending on the soil type, climatological data and crop data (Trivedi et al., 2018). This software can evaluate irrigation practices adopted by farmers and can also estimate the performance of crops under both irrigation and rain fedconditions.

2. THE STUDY AREA

The Sone command area aggregate catchment zone of the waterway is 71,259 sq. km, of which 25 percent lies in Bihar. Out of this 25 percentage of the catchment area in Bihar, 8600 km^2 fall in the Sone command area. The remaining 53,608 sq. km lies in Chhattisgarh, Madhya Pradesh, Uttar Pradesh and Jharkhand states of India. The stream is a tributary of the waterway Ganga. The zone gets around 1100 mm of rainfall, more than 80 percent of the rainy season is during June to September. The most of the soils are alluvial and vary from light to heavy- textured clays in the top layer with coarse substrata. The Sone command area is plain in geography; it consistently slants towards the Ganga River. The above features make the zone perfect for watered (irrigation) farming.

Paliganj Distributary is part of the Sone Canal System in South Bihar. The Sone River flows northeastward from the Deccan Plateau before joining the Ganges not far from the city of Patna. The Sone Canal System diverts water from the river to irrigate a design command area of over 700,000 ha. The Paliganj distributary is a branch of Patna Canal, 75 km in the downstream direction from its head from Sone Barrage. Chandos and Bharatpura being its two sub- distributaries. The complete length of this system (including sub distributaries) is around 40 km and a total of 4500 ha of agricultural land is irrigated by it. Channels of this system meander through Paliganj and Dulhania Bazar blocks in Patna and Arwal block of Arwal district which incorporates more than 50 villages.

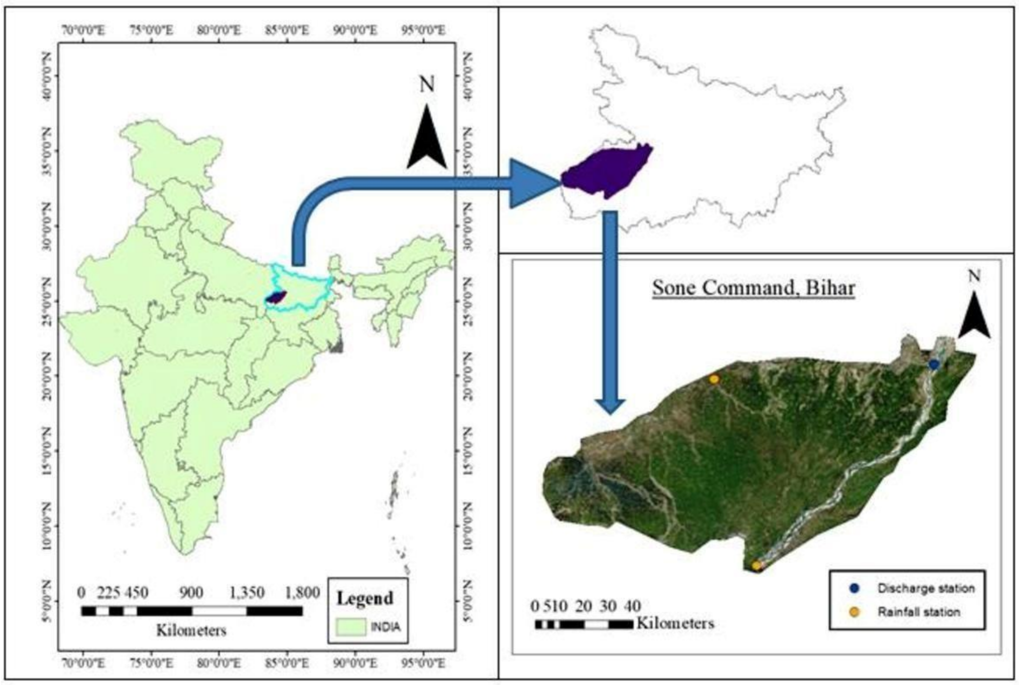

Fig-1: Sone Command Area (**Source:** Kumar et al 2019)

Soils

Soils generally found in the study area are sandy loam with clay loam at places having low to medium nutrient status with pH value ranging from 6.3 to 8.2. On the basis of mode of deposition, soils are divided into three groups: (i) Recent alluvium (ii) Tal and (iii) Older alluvium. The soils of the region have developed due to weathering action on alluvial deposits transported from relatively younger geological formations.

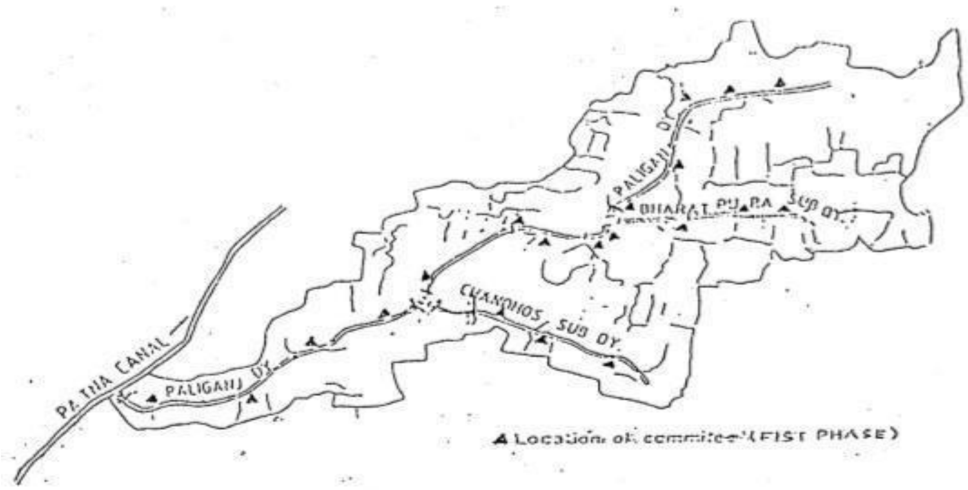

Figure-2: Index Map of Paliganj Distributary (**Source:** Bihar State Second Irrigation Commission)

Data collection

For calculating evapotranspiration, weather data for the time period (1999-2015) of study area were collected from IMD, Indian Water Portal, Govt. of India (www.imd.gov.in) and from the website of Weather & Climate (www.weather-and-climate.com) is given in table-4.

3. METHODOLOGY

Reference Evapotranspiration (ET_o)

Reference evapotranspiration (ET_o) is the rate from a reference surface that is grasses of uniform height of 12 cm, not shortage of water, not diseased and in extensive field. It has been analyzed using Penman-Monteith method.

$$ET_o = \left[\frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T+273} \times U_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 . U_2)}\right] \quad (1)$$

Where, T is the mean daily air temperature (°C); Δ is the slope saturation vapor curve (kPa/°C); R_n is the net radiation at the crop surface (MJ/m^2/day); γ is the psychometric constant (kPa/°C); G is the soil heat-flux density (MJ/m^2/day); e_a is the actual vapor pressure (kPa); e_s - e_a is the saturation vapor pressure deficit (kPa); U_2 is the wind speed (m/s) at 2 m height; and e_s is the saturation vapor pressure (kPa).

Crop Evapotranspiration (ET_c)

The requirement of water for proper growth of different crops is different which depends on the type of crop and the period for which the crop is grown along with the existing weather conditions. This crop water requirement is met from all sources of water available i.e. precipitation, irrigation water available from underground water table etc.

Table-1: Crop Coefficient K_c and maximum plant height in ideal conditions for use with Penman-Monteith ET_0 (Source: FAO 56)

Crop	K_c (ini)	K_c (mid)	K_c (end)	Max. crop height, h (m)
Wheat	0.7	1.15	0.4	1
Maize	-	1.20	0.60	2

The yield stress is calculated using the following equation (Doorenbos and Kassam, 1979)

$$\frac{Y}{Ym} = \left[1 - Ky \times [1 - \frac{ETa}{ETm}]\right] \quad (2)$$

Where,
y = The actual crop yield;
y_m = The maximum crop yield;
ET_a = Actual rate of Evapotranspiration;
ET_m = Maximum rate of Evapotranspiration; and
k_y = yield response factor of crop

Table-2: Yield response factor k_y for the different growth stage (Source: Doorenbos and Kassam 1979)

Crop	Vegetative period	Flowering period	Grain formation	Ripening
Wheat	0.2	0.6	0.5	-
Maize	0.4	1.5	0.5	0.2

Water production functions of crops

Jensen et al., (1968) Model

$$\frac{Y}{Y_m} = \prod_{i=1}^{N} (\frac{ET_a}{ET_m})^{\lambda_i} \quad (3)$$

Where, *i* denote different stage of growth; Y, ETa is the crop yield and actual crop evapotranspiration from stressed condition; Ym, ETm is the crop yield and actual crop evapotranspiration from non-stress condition; λ is the moisture sensitivity factor; and n is the number of growth stages.

Minhas et al., (1974) Model

$$\frac{Y}{Y_m} = \prod_{i=1}^{N} [1 - (1 - \frac{ET_a}{ET_m})_i^2]^{\lambda_i} \quad (4)$$

Stewart et al., (1976) Model

$$\frac{Y}{Y_m} = 1 - \sum_{i=1}^{N} K_i \, (1 - \frac{ET_a}{ET_m})_i \qquad (5)$$

Where, K_i is the crop yield response corresponding to stage i

Rao et al., (1988) Model

$$\frac{Y}{Y_m} = \prod_{i=1}^{N} [1 - K_i \, (1 - \frac{ET_a}{ET_m})_i \qquad (6)$$

Table-3: **Values of λ_i corresponding to different values of K_i(Source: Tsakiris, 1982)**

K_i	0.20	0.25	0.30	0.40	0.45	0.50	1.55	0.60	0.75	0.80	1.00	1.50
λ_i	0.15	0.19	0.24	0.32	0.37	0.42	0.47	0.52	0.68	0.74	1.00	1.95

4. RESULTS AND DISCUSSION

Crop water requirements are found with help of CROPWAT 8.0 for different crops. It gives the values of Kc and ET_c corresponding to different growth stage of crop. Variation in value of ET_o with change in value of different parameters is shown with the help of graphs.

Table-4: Climate characteristics, rainfalls, and ET_o of Patna (average for 1999–2015 period) obtained using the CROPWAT software.

Name of Month	Temp°C (Min.)	Temp.°C (Max.)	Relative Humidity in %	Wind Speed in km/day	Actual Sunshine in hrs	Radiation in MJ/m^2/day	ET_o in mm/day	Average Rainfall in mm
January	8.51	21.35	74.73	60.3	3	9.3	1.57	20.4
Feb.	12.06	26.15	67.45	73.62	5.75	14.2	2.45	11.1
March	16.52	32.61	51.93	91.25	7.55	18.8	3.99	11.4
April	21.82	37.33	46.36	132.34	7.06	19.8	5.47	9
May	25.15	37.25	54.16	151.52	7.12	20.6	5.9	35.6
June	26.53	35.98	64.85	143.28	6.07	19.2	5.29	141
July	25.58	33.23	74.42	120.88	4.69	17	4.28	319.2
August	26.66	33.17	75.84	123.12	3.79	15.1	3.88	279.3
Sept.	26.18	32.7	74.18	104.39	6.05	17.2	4.11	212.6
October	22.08	32.01	70.84	65.03	6.31	15.5	3.42	72.3
Nov.	14.49	28.8	66.97	42.06	4.18	11	2.25	8.2
Dec.	10.54	23.83	69.7	41.06	2.2	8	1.59	7.4
Avg.	19.68	31.2	65.95	95.74	5.3	15.48	3.68	93.96

Table-5: ET_o (mm/day) values for ICAR Farm at Patna for the Period 1999-2015

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1999	1.65	2.51	3.97	5.73	5.85	5.7	4.15	3.7	4.09	3.28	2.11	1.59
2000	1.55	2.2	3.82	5.39	5.33	4.6	4.03	3.71	3.98	3.61	2.34	1.6
2001	1.54	2.3	3.31	4.25	5.38	4.53	3.94	3.42	3.91	3.54	2.08	1.36
2002	1.56	2.19	3.6	5.06	5.13	4.81	4.06	3.61	4.02	3.63	2.2	1.54
2003	1.31	2.06	3.43	4.59	5.23	4.98	4.41	3.5	4.06	3.3	2.13	1.49
2004	1.3	2.18	3.78	4.64	5.58	4.97	3.95	3.46	4.27	3.63	2.44	1.65
2005	1.69	2.49	3.96	4.82	5.11	4.96	4.01	3.46	4.01	3.33	2.12	1.52
2006	1.98	2.66	4.99	5.73	4.81	4.45	3.59	3.52	2.67	2.58	2.11	1.83
2007	1.59	2.27	3.7	5.28	6.07	5.31	3.94	3.74	4.08	3.39	2.1	1.49
2008	1.66	1.97	3.9	5.39	5.91	4.73	3.98	3.72	4.24	3.51	2.08	1.39
2009	1.64	3	4.07	6.07	6.57	6.85	5.78	4.91	5.17	3.66	2.39	1.86
2010	1.67	2.75	4.45	6.25	6.34	6.21	4.81	4.56	4.08	3.33	2.65	1.93
2011	1.72	2.73	4.25	5.45	6.15	5.4	4.68	4.42	4.04	3.41	2.58	1.68
2012	1.81	2.58	4.16	5.52	6.09	5.23	4.55	4.1	3.7	3.37	2.45	1.86
2013	1.47	2.36	3.9	5.15	5.2	4.34	4.24	4.19	4.1	2.93	2.25	1.6
2014	1.32	2.09	3.77	5.8	6.19	5.17	3.97	3.58	3.69	3.14	2.35	1.31
2015	1.37	2.31	3.68	4.73	5.91	5.53	4.06	3.6	4.31	3.51	1.92	1.42

In Table-5 ET_o values for years 1999-2015 are tabulated. In Table-6 these values are sorted in ascending order to allot them rank 'm'. Dependable ET_o is calculated by Weibull Formula m / (n+1) where m is rank and n is total number of values tabulated in last column. For calculation purpose dependable value of ET_o, 75% the value of ET_o of the month may is considered (May being the hottest month is selected).

Table-6: Estimation of Dependable ET_o ICAR Farm at Patna for the Period (1999-2015)

m	Jan	Feb	Mar.	April	May	June	July	Aug	Sept	Oct	Nov	Dec	(m/(n+1))*100
1	1.3	1.97	3.31	4.25	4.81	4.34	3.59	3.42	2.67	2.58	1.92	1.31	5.56
2	1.31	2.06	3.43	4.59	5.11	4.45	3.94	3.46	3.69	2.93	2.08	1.36	11.11
3	1.32	2.09	3.6	4.64	5.13	4.53	3.94	3.46	3.7	3.14	2.08	1.39	16.67
4	1.37	2.18	3.68	4.73	5.2	4.6	3.95	3.5	3.91	3.28	2.1	1.42	22.22
5	1.47	2.19	3.7	4.82	5.23	4.73	3.97	3.52	3.98	3.3	2.11	1.49	27.78
6	1.54	2.2	3.77	5.06	5.33	4.81	3.98	3.58	4.01	3.33	2.11	1.49	33.33
7	1.55	2.27	3.78	5.15	5.38	4.96	4.01	3.6	4.02	3.33	2.12	1.52	38.89
8	1.56	2.3	3.82	5.28	5.58	4.97	4.03	3.61	4.04	3.37	2.13	1.54	44.44
9	1.59	2.31	3.9	5.39	5.85	4.98	4.06	3.7	4.06	3.39	2.2	1.59	50
10	1.64	2.36	3.9	5.39	5.91	5.17	4.06	3.71	4.08	3.41	2.25	1.6	55.56
11	1.65	2.49	3.96	5.45	5.91	5.23	4.15	3.72	4.08	3.51	2.34	1.6	61.11
12	1.66	2.51	3.97	5.52	6.07	5.31	4.24	3.74	4.09	3.51	2.35	1.65	66.67
13	1.67	2.58	4.07	5.73	6.09	5.4	4.41	4.1	4.1	3.54	2.39	1.68	72.22
14	1.69	2.66	4.16	5.73	6.15	5.53	4.55	4.19	4.24	3.61	2.44	1.83	77.78
15	1.72	2.73	4.25	5.8	6.19	5.7	4.68	4.42	4.27	3.63	2.45	1.86	83.33
16	1.81	2.75	4.45	6.07	6.34	6.21	4.81	4.56	4.31	3.63	2.58	1.86	88.89
17	1.98	3	4.99	6.25	6.57	6.85	5.78	4.91	5.17	3.66	2.65	1.93	94.44

Table-7: Crop Water Requirement of Maize

Name of Month	Decade(s)	Stage	K_c	ET_c in mm/day	ET_c in mm/dec	Effective rainfall in mm/dec	Irrigation requirement in mm/dec
Jul.	2	Init.	0.3	1.29	2.6	18.7	2.6
Jul.	3	Init.	0.3	1.24	13.7	87.1	0
Aug.	1	Deve.	0.32	1.27	12.7	78.7	0
Aug.	2	Deve.	0.52	2.01	20.1	75.5	0
Aug.	3	Deve.	0.79	3.12	34.3	69.2	0
Sep.	1	Deve.	1.06	4.34	43.4	64.5	0
Sep.	2	Mid	1.2	5.05	50.5	59.4	0
Sep.	3	Mid	1.2	4.74	47.4	46.1	1.3
Oct.	1	Mid	1.2	4.38	43.8	29.9	14
Oct.	2	Mid	1.2	4.11	41.1	16.4	24.7
Oct.	3	Late	1.08	3.29	36.2	11.7	24.5
Nov.	1	Late	0.84	2.22	22.2	6	16.1
Nov.	2	Late	0.6	1.36	13.6	0	13.6
					381.5	563.1	96.8

Table-8: Yield Reduction for Maize

Stage	Init.	Deve.	Mid	Late	Season
Percentage Change in ETc	0	0	0	0	0
Yield Response factor (k_y)	0.40	1	1.3	0.50	1.25
Reduction in Yield (%)	0	0	0	0	0

Calculation of expected yield for Maize at the end of different growth stages

Table-9: Data for calculation of Yield Reduction for ET_{a} = 90% of ET_c (ET_a value is equal to 10 % reduced value of ET_c)

Growth Stage	***ET*** $_c$**(mm/day)**	***ET*** $_a$ **(mm/day)**	K_y	λ_i
Initial	1.27	1.14	0.4	0.32
Development	2.69	2.42	1	1
Mid	4.57	4.11	1.3	1.57
Late	2.29	2.1	0.5	.42

1. Yield reduction as per Jensen et al., (1968)model

$$\frac{Y}{Y_m} = (\frac{ET_a}{ET_m})^{\lambda_1} * (\frac{ET_a}{ET_m})^{\lambda_2} * (\frac{ET_a}{ET_m})^{\lambda_3} * (\frac{ET_a}{ET_m})^{\lambda_4} \quad (7)$$

$$\frac{Y}{Y_m} = (\frac{1.14}{1.27})^{.32} * (\frac{2.42}{2.69})^{1} * (\frac{4.11}{4.57})^{1.57} * (\frac{2.1}{2.29})^{.42}$$

= (.966) (.900) (.847) (.964) = 0.71

Yield reduction = $1 - \frac{Y}{Y_m}$ = 1 - .71 =0.29

So, Yield Reduction = 29 %

2. Yield reduction as per Minhas et al., (1974) model

$$\frac{Y}{Y_m} = \prod_{i=1}^{N}[1 - (1 - \frac{ET_a}{ET_m})_i^2]^{\lambda_i} \quad (8)$$

$$\frac{Y}{Y_m} = [1 - (1 - \frac{1.14}{1.27})^2]^{.32} * [1 - (1 - \frac{2.42}{2.69})^2]^{1} * [1 - (1 - \frac{4.11}{4.57})^2]^{1.57} * [1 - (1 - \frac{2.1}{2.29})^2]^{.42}$$

$\frac{Y}{Y_m}$ = (.997) (.990) (.984) (.997) = 0.968

Yield reduction = $1 - \frac{Y}{Y_m}$ = 1 - 0.968 = 0.0316

So, Yield Reduction = 3.16 %

3. Yield reduction as per Stewart et al., (1976) model

$$\frac{Y}{Y_m} = 1 - \sum_{i=1}^{N} K_i\,(1 - \frac{ET_a}{ET_m})_i \quad (9)$$

$$\frac{Y}{Y_m} = 1 - [.4\left(1 - \frac{1.14}{1.27}\right) * 1\left(1 - \frac{2.42}{2.69}\right) * 1.57\left(1 - \frac{4.11}{4.57}\right) * .42\left(1 - \frac{2.1}{2.29}\right)]$$

=1-[(.04) (.10) (.13) (.05)] = 0.68

Yield reduction = $1 - \frac{Y}{Y_m}$ = 1 - 0.68 = 0.32

So, Yield Reduction = 32 %

4. Yield reduction as per Rao et al., (1988) model

$$\frac{Y}{Y_m} = \prod_{i=1}^{N}[1 - K_i\left(1 - \frac{ET_a}{ET_m}\right)_i] \quad (10)$$

$$= [1-.4\left(1 - \frac{1.14}{1.27}\right)] * [1 - 1\left(1 - \frac{2.42}{2.69}\right)] * [1 - 1.3\left(1 - \frac{4.11}{4.57}\right)] * [1 - .5\left(1 - \frac{2.1}{2.29}\right)]$$

= (.959) (.899) (.869) (.958) = 0.7177

Yield reduction = $1 - \frac{Y}{Y_m}$ = 1 - 0.718 = 0.282

So, Yield Reduction = 28.2 %

Similarly, calculation of Yield Reduction for ET_{ac} equivalent to 20 %, 30 %, 40 % and 50 % reduction in ET_c is done.

Table-10: % Reduction in Yield of Maize with % reduction in ET_c

Reduction in ET_c%	**10**	**20**	**30**	**40**	**50**
Jensen et al., (1968) Model	29	52.2	69.3	81.6	89.9
Minhas et al., (1974) Model	3.16	12.63	26.81	43.84	61.41
Stewart et al., (1976) Model	32	64	96	100	100
Rao et al., (1988) Model	28.2	51	68	80.6	89.9

Similarly, calculation of Yield Reduction for ET_a equivalent to 20 %, 30 %, 40 % and 50 % reduction in ET_c is done.

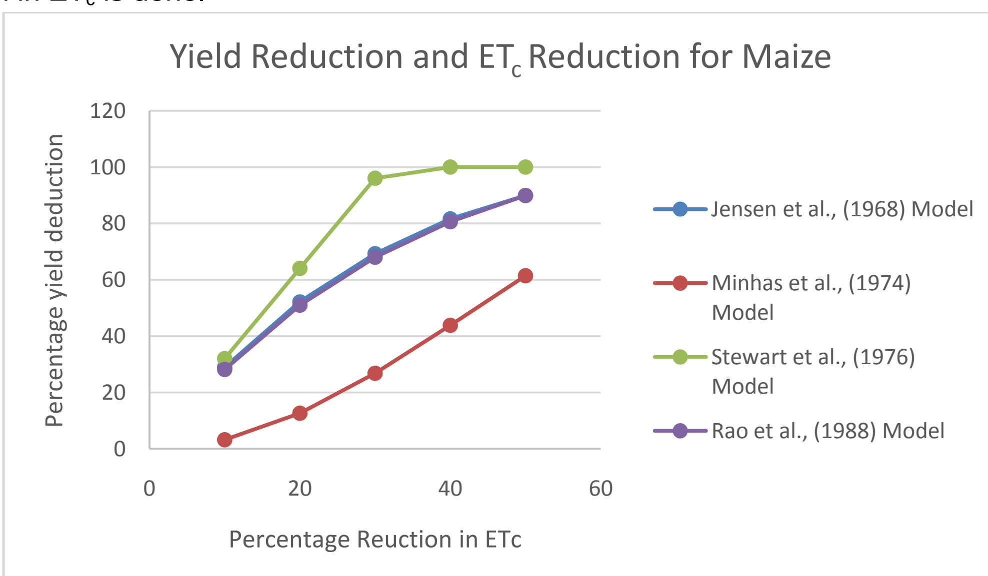

Figure-3: Yield Reduction with respect to ET_c Reduction for Maize

Table-11: Crop Water Requirements of Wheat crop

Name of Month	Decade(s)	Stage	K_c	ET_c in mm/day	ET_c in mm/dec	Effective rainfall in mm/dec	Irrigation Requirement in mm/dec
Dec.	1	Init.	0.7	1.27	12.7	1.7	11
Dec.	2	Init.	0.7	1.11	11.1	1.5	9.7
Dec.	3	Deve.	0.76	1.21	13.3	2.8	10.5
Jan.	1	Deve.	0.9	1.36	13.6	4.8	8.7
Jan.	2	Deve.	1.03	1.51	15.1	6.2	8.8
Jan.	3	Mid.	1.14	2.04	22.5	5.1	17.3
Feb.	1	Mid.	1.15	2.48	24.8	3.6	21.2
Feb.	2	Mid.	1.15	2.82	28.2	2.6	25.5
Feb.	3	Late	1.09	3.24	25.9	2.8	23.2
Mar.	1	Late	0.9	3.14	31.4	3	28.3
Mar.	2	Late	0.69	2.75	27.5	3.1	24.4
Mar.	3	Late	0.49	2.18	19.6	2.3	16.7
					245.5	39.6	205.4

Table-12: Percentage Reduction in Yield of Wheat with percentage reduction in ET_c

Reduction in ET_c%	**10**	**20**	**30**	**40**	**50**
Jensen et al., (1968) Model	12.16	24.17	35.74	46.92	57.67
Minhas et al., (1974) Model	1.2	4.94	11.04	19.44	30
Stewart et al., (1976) Model	15	30	45	60	75
Rao et al., (1988) Model	14.14	27.01	38.41	48.53	57.47

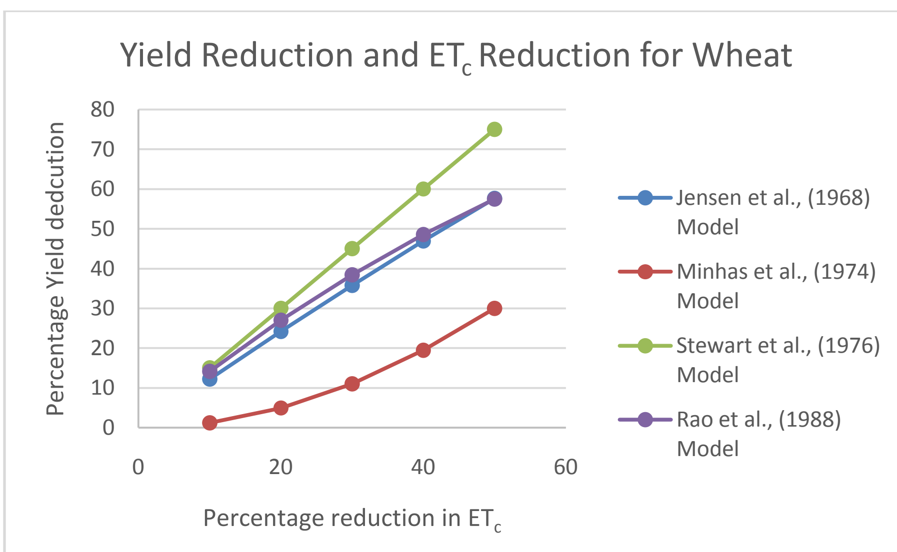

Figure-4: Yield Reduction with respect ET_c for Wheat

The results reveal that the crop water requirement is influenced by climatological conditions, rainfall, and soil and crop characteristics. The difference between Actual Evapotranspiration (ET_a) and Crop Evapotranspiration (ET_c) causes reduction in yield of crop. In the Sone Command Area, the value of K_s water stress coefficient is ≈ 1. There is not much of water stress in this area.
With the help of water production function models the timely effect on crop growth corresponding to water deficit is studied. The results show that 10 % reduction in ET_ain comparison to ET_c is tolerable but if this reduction is 20% or more, it affects the crop yield drastically.

5. CONCLUSIONS

From the above results and discussions different conclusions are made and some recommendations are listed below

1. Study suggests that in the future the demand of water is going to be high in comparison with the water available for irrigation. Deficit irrigation can help in coping up with this kind of situation.
2. CROPWAT 8.0 decision support tool gives an accurate estimation of reference evapotranspiration considering all the meteorological data and it is very effective in calculating crop water requirements, yield reduction and irrigation scheduling.
3. From the graphical comparison of the maize and wheat crop outputs of the crop water production functions in Figure 9 and Figure 10,at 10% reduction in ET_c, the Jensen, Stewart et al. and Rao et al. models give tolerable values, but reduction in ET_c is 20% or more, the Jensen and Rao at al. models give reliable values as compared to other two models. Therefore, the Jensen and Rao at al. models are reliable to monitor crop yield response to deficit in availability of water.

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