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Water Production Function under Different Irrigation Schedules for Wheat Crop using CROPWAT Model

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Abstract The simulation study was conducted with the objective of determining the water production function under different irrigation schedules viz., I_1 (CRI, TL, BT, FL, ML, SD), I_2 (0.4 IW: CPE ratio), I_3 (0.6 IW : CPE ratio), I_4 (0.8 IW : CPE ratio) and I_5 (1.0 IW : CPE ratio). The CROPWAT simulated the lowest ET_c and yield reduction under I_1 treatment (3.6%) and lowest K_y (0.0) value as compared to other treatment under fixed irrigation interval. Results revealed that at 100% critical depletion the yield was not reduced but critical depletion level increased there is slightly reduced in yield. The cumulative yield reduction (%) for fixed depletion of 100 to 150 mm was 6.4, 7.9, 9.9, 13.1, 17 and 22.3% respectively. The minimum yield reduction occurred at 5% reduction per stage (4.1%) where as the maximum at 50% (47.5%) in wheat crop.

Keywords Water production function (K_y), Irrigation schedules, CROPWAT model, Irrigation approaches, Wheat crop.

Introduction

Dwindling water resources and increasing food requirements require greater efficiency in water use, both in rainfed and in irrigated agriculture. Regulated deficit irrigation provides a means of reducing water consumption while, minimizing adverse effects on yield. Models can play a useful role in developing practical recommendations for optimizing crop production under conditions of scarce water supply. The CROPWAT model was developed by the FAO land and water development division includes a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for determination of crop evapotranspiration and yield responses to water. The CROPWAT model can adequately predict the effect of water stress, but requires the calibration of the main crop parameters. The CROPWAT model is a powerful tool or extending findings and conclusion to conditions not tested in the field and that useful predictions on deficit irrigation scheduling are possible under various conditions of water supply, soil and crop management. Deficit irrigation can play an important role in increasing water use efficiency WUE=Yield (kg/ha)/ET (mm). The objective of regulated deficit irrigation is to save water by subjecting crops to periods of moisture stress with minimal effects of yields. The effects of stress on yields are complex and may differ with species, cultivar and growth stages ; they have been the subject of many studies. Reduction in ET_c during initial stage of crop was not affecting negatively on final yield. The reductions in ET_c during mid and late stage that negatively affecting final yield of wheat also studied [1]. CROPWAT facilitates the estimation of the crop evapotranspiration, crop water requirements and irri-

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Table 1. Yield reduction phase wise under irrigation criteria of irrigate at fixed interval.

	Treatments	Particulars	Wheat stages Initial	Deve-lop-ment	Mid	Late	Season
I_1	(CRI, TL, BT, FL, ML and DS)	Yield response factor	0.2	0.6	0.5	0.4	1
		Reduction in Et_c (mm)	26	0	0	0	3.6
		Yield reduction (%)	5.2	0	0	0	0
		Cumulative yield reduction (%)	5.2	5.2	5.2	5.2	3.6
I_2	(0.4 IW : CPE)	Reduction in Et_c (mm)	26	8.5	30.5	7.2	20
		Yield reduction (%)	5.2	5.1	15.3	2.9	0
		Cumulative yield reduction (%)	5.2	10	23.8	25.9	20
I_3	(0.6 IW : CPE)	Reduction in Et_c (mm)	26	6.5	9.3	4.8	10.1
		Yield reduction (%)	5.2	3.9	4.7	1.9	0
		Cumulative yield reduction (%)	5.2	8.9	13.1	14.8	10.1
I_4	(0.8 IW : CPE)	Reduction in Et_c (mm)	26	1.6	0	0	4.1
		Yield reduction (%)	5.2	0.9	00	0	0
		Cumulative yield reduction (%)	5.2	6.1	6.1	6.1	4.1
I_5	(1.0 IW : CPE)	Reduction in Et_c (mm)	26	0.5	0	0	3.8
		Yield reduction (%)	5.2	0.3	0	0	0
		Cumulative yield reduction (%)	5.2	5.5	5.5	5.5	3.8

gation schedule with different cropping patterns for irrigation planning [2—7]. Similar results showed that phase wise reduction in cumulative yield was 3.9, 9.1, 14.6 and 19.3% under S_1 to S_2 moisture regime was simulated by model for S_1 (CRI + 100 mm CPE), S_2 (CRI + 150 mm CPE), S_3 (CRI+200 mm CPE) and S_4 (CRI) treatments respectively [8]. The use of simulation model is the absence of validation of such model in areas other than where they are developed. Before their application on a regional scale in different regions, they need standardization and calibration with locally conditions.

Materials and Methods

An experiment was conducted at Agronomy Farm, Anand Agricultural University, Anand during *rabi* season of 2011–2012. India situated at 22°35´ N latitude and 72°55´ E longitude and at an altitude of 45.1 m above mean sea level. The treatment comprised of five levels of irrigation schedule viz. I_1 (CRI, TL, BT, FL, ML, SD), I_2 (0.4 IW : CPE ratio), I_3 (0.6 IW : CPE ratio), I_4 (0.8 IW : CPE ratio) and I_5 (1.0 IW : CPE ratio). The CROPWAT model was being calibrated using crop, soil and weather data and subsequently yield response factor (water production function) was worked out. After through calibration of model, the other irrigation schedule method was simulated for comparison. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and as-

Table 2. Crop water production function irrigation criteria of irrigate at fixed interval using CROPWAT model.

Irrigation treatments	Yield (t ha^{-1})	ET_a (mm)	ET_a / ET_m	Y_a / Y_m	1–(ET_a / ET_m)	1–(Y_a / Y_m)	K_y
I_1	4.38	246.19	0.847	1.000	0.153	0.000	0.000
I_2	3.60	203.19	0.699	0.822	0.301	0.178	0.592
I_3	4.09	229.85	0.791	0.933	0.209	0.067	0.319
I_4	4.11	238.86	0.822	0.939	0.178	0.061	0.341
I_5	4.18	245.88	0.846	0.954	0.154	0.046	0.299

Table 3. Yield reduction phase wise under irrigation criteria of irrigate at critical depletion.

Particulars	Initial	Wheat stages Development	Mid	Late	Season
Reduction in Et_c (mm)	0.0	0.0	0.0	0.0	0.0
Yield response factor	0.2	0.6	0.5	0.4	1.0
Yield reduction (%)	0.0	0.0	0.0	0.0	0.0
Cumulative yield reduction (%)	0.0	0.0	0.0	0.0	0.0

sessment of production under rainfed conditions or deficit irrigation. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO irrigation and drainage papers no. 24 crop water requirements and no. 33 yield response to water. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions.

Meteorological data

Climate data : The meteorological data were collected for two years (2011–2012) from Agricultural Meteorology observatory, AAU, Anand. These data include daily maximum and minimum temperature, daily relative humidity, daily wind speed and daily sunshine hours. The daily average of all these data were calculated and used in the model.

Crop data

The software needs some information about wheat crops i.e. crop name, planting date, harvesting date, crop coefficient (K_c), rooting depth, length of plant growth stages, critical depletion and yield response factor. Sowing date for wheat was considered as November 15 and harvest date March 13.

Soil data

Presence of sand silt and clay in various proportions determines the type of soil and its moisture holding capacity. The soil type is loamy sand with alluvial in origin and belongs to Entisols. The software needs

Table 4. Yield reduction phase wise under irrigation criteria of irrigate at above critical depletion.

Critical depletion (%)	Particulars	Initial	Wheat stages Development	Mid	Late	Season
110	Yield response factor	0.2	0.6	0.5	0.4	1.0
	Reduction in Et_c (mm)	0.8	0.9	1.5	0.0	1.0
	Yield reduction (%)	0.2	0.5	0.7	0.0	0.0
	Cumulative yield reduction (%)	0.2	0.7	1.4	1.4	1.0
120	Reduction in Et_c (mm)	3.8	5.1	6.2	0.0	4.5
	Yield reduction (%)	0.8	3.0	3.1	0.0	0.0
	Cumulative yield reduction (%)	0.8	3.8	6.8	6.8	4.5
130	Reduction in Et_c (mm)	11.3	11.4	12.6	16.3	12.8
	Yield reduction (%)	2.3	6.9	6.3	6.5	0.0
	Cumulative yield reduction (%)	2.3	9.0	14.7	20.3	12.8
140	Reduction in Et_c (mm)	26	16.6	27.8	0.0	19.6
	Yield reduction (%)	5.2	9.9	13.9	0.0	0.0
	Cumulative yield reduction (%)	5.2	14.6	26.5	26.5	19.6

Table 5. Crop water production function (K_y) irrigation criteria of irrigate at above critical depletion.

Critical depletion (%)	Yield (t ha^{-1})	ET_a (mm)	ET_a / ET_m	Y_a / Y_m	1–(ET_a / ET_m)	1–(Y_a / Y_m)	Ky
110	4.336	253.16	0.871	0.990	0.129	0.010	0.078
120	4.182	244.22	0.840	0.955	0.159	0.045	0.283
130	3.819	223.08	0.768	0.872	0.232	0.128	0.551
140	3.521	205.87	0.708	0.804	0.291	0.196	0.672

some general soil data like total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture.

The calculation of reference evapotranspiration ($ET_○$) is based on the FAO penman-monteith method. Input data include monthly and daily temperature (maximum and minimum), humidity, sunshine and wind-speed. Crop water requirements (ET_{crop}) over the growing season are determined from $ET_○$ and estimates of crop evaporation rates, expressed as crop coefficients (K_c) based on well-established procedures according to the following equation.

$$ET_{crop} = K_c \times ET_○ \text{ or } K_c = ET_c / ET_○$$

FAO penman-monteith equation

Table 6. Yield reduction phase wise under irrigation criteria of irrigate at fixed depletion.

Fixed depletion (mm)	Particulars	Wheat stages Initial	Development	Mid	Late	Season
100 mm	Yield response factor	0.2	0.6	0.5	0.4	1.0
	Reduction in Et_c (mm)	26	10.7	0.0	0.0	6.4
	Yield reduction (%)	5.2	6.4	0.0	0.0	0.0
	Cumulative yield reduction (%)	5.2	11.3	11.3	11.3	6.4
110 mm	Reduction in Et_c (mm)	26	16.6	0.0	0.0	7.9
	Yield reduction (%)	5.2	9.9	0.0	0.0	0.0
	Cumulative yield reduction (%)	5.2	14.6	14.6	14.6	7.9
120 mm	Reduction in Et_c (mm)	26	23.2	0.8	0.0	9.9
	Yield reduction (%)	5.2	13.9	0.4	2.6	0.0
	Cumulative yield reduction (%)	5.2	18.4	18.7	18.7	9.9
130 mm	Reduction in Et_c (mm)	26	29.7	4.0	0.9	13.1
	Yield reduction (%)	5.2	17.8	2.0	0.4	0.0
	Cumulative yield reduction (%)	5.2	22.1	23.6	23.9	13.1
140 mm	Reduction in Et_c (mm)	26	35.2	9.9	0.8	17
	Yield reduction (%)	5.2	21.1	4.9	0.3	0.0
	Cumulative yield reduction (%)	5.2	25.2	28.9	29.1	17.0
150 mm	Reduction in Et_c (mm)	26	40.6	19.5	0.0	22.3
	Yield reduction (%)	5.2	24.4	9.8	0.0	0.0
	Cumulative yield reduction (%)	5.2	28.3	35.3	35.3	22.3

Table 7. The crop water production function (K_y) irrigation criteria at irrigate at fixed depletion using CROPWAT model.

Depletion (%)	Yield (t ha^{-1})	ET_a (mm)	ET_a / ET_m	Y_a / Y_m	1–(ET_a / ET_m)	1–(Y_a / Y_m)	K_y
100	4.099	239.21	0.823	0.936	0.177	0.064	0.363
110	4.033	235.33	0.810	0.921	0.190	0.079	0.416
120	3.946	230.35	0.793	0.901	0.207	0.099	0.478
130	3.806	222.14	0.764	0.869	0.236	0.131	0.555
140	3.635	212.19	0.730	0.830	0.270	0.170	0.630
150	3.403	198.99	0.684	0.777	0.316	0.223	0.706

$$ET_{\circ} = \frac{0.408\Delta (R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34\, u_2)}$$

Where, $ET_{\circ}$ – Reference evapotranspiration [mm day^{-1}], R_n–Net radiation at the crop surface [MJ m^{-2} day^{-1}], G–Soil heat flux density [MJ m^{-2} day^{-1}], T–Mean daily air temperature at 2 m height [C], u_2–Wind

Table 8. Yield reduction phase wise under irrigation criteria of irrigate at given ET crop per stage.

ET_c reduction per stage (%)	Particulars	Wheat stages: Initial	Development	Mid	Late	Season
5	Yield response factor	0.2	0.6	0.5	0.4	1.0
	Reduction in Et_c (mm)	1.6	5.5	5.8	0.0	4.1
	Yield reduction (%)	0.3	3.3	2.9	0.0	0.0
	Cumulative yield reduction (%)	0.3	3.6	6.4	6.4	4.1
10	Reduction in Et_c (mm)	3.8	13.4	10.1	3.7	8.9
	Yield reduction (%)	0.8	8.0	5.0	1.5	0.0
	Cumulative yield reduction (%)	0.8	8.7	13.3	14.6	8.9
25	Reduction in Et_c (mm)	23.9	8.9	34.5	0.0	20.2
	Yield reduction (%)	4.8	5.3	17.2	0.0	0.0
	Cumulative yield reduction (%)	4.8	9.9	25.4	25.4	20.2
30	Reduction in Et_c (mm)	26	13.8	40.9	20.4	28.2
	Yield reduction (%)	5.2	8.3	20.5	8.2	0.0
	Cumulative yield reduction (%)	5.2	13.1	30.9	36.5	28.2
35	Reduction in Et_c (mm)	26	23.0	43.7	20.3	31.7
	Yield reduction (%)	5.2	13.8	21.9	8.1	0.0
	Cumulative yield reduction (%)	5.2	18.3	36.2	41.3	31.7
40	Reduction in Et_c (mm)	26	42.1	43.2	10.5	34.6
	Yield reduction (%)	5.2	25.3	21.6	4.2	0.0
	Cumulative yield reduction (%)	5.2	29.2	44.5	46.8	34.6
45	Reduction in Et_c (mm)	26	49.7	45.4	31.2	41.2
	Yield reduction (%)	5.2	29.8	22.7	12.5	0.0
	Cumulative yield reduction (%)	5.2	33.4	48.5	55	41.2
50	Reduction in Et_c (mm)	26.0	49.7	53.4	47.1	47.5
	Yield reduction (%)	5.2	29.8	26.7	18.8	0.0
	Cumulative yield reduction (%)	5.2	33.4	51.2	60.4	47.5

Table 9. The water production function (K_y) irrigation criteria of irrigate at ET crop reduction per stage.

ET_c reduction per stage (%)	Yield (t ha^{-1})	ET_a (mm)	ET_a / ET_m	Y_a / Y_m	1–(ET_a / ET_m)	1–(Y_a / Y_m)	K_y
5	4.210	245.16	0.844	0.961	0.156	0.038	0.248
10	3.990	233.19	0.802	0.911	0.198	0.089	0.450
25	3.490	204.43	0.703	0.797	0.297	0.203	0.685
30	3.140	184.34	0.634	0.717	0.366	0.283	0.774
35	2.990	175.12	0.603	0.683	0.397	0.317	0.798
40	2.860	168.02	0.578	0.653	0.422	0.347	0.823
45	2.570	151.25	0.520	0.587	0.480	0.413	0.862
50	2.290	134.84	0.464	0.523	0.536	0.477	0.890

speed at 2 m height [m s^{-1}], es–Saturation vapor pressure [k Pa], ea–Actual vapor pressure [k Pa], es–ea saturation vapor pressure deficit [k Pa], D–Slope vapor pressure curve [k Pa °C–1] ND g–Psychrometric constant [k Pa °C-1].

FAO has presented updated values for crop coefficients. Through estimates of effective rainfall, crop irrigation requirements are calculated assuming optimal water supply. With inputs on soil water retention and infiltration characteristics and estimates of rooting depth, a daily soil water balance was calculated, predicting water content in the rooted soil by means of a water conservation equation, which takes into account the incoming and outgoing flow of water. Stress conditions in the root zone are defined by the critical soil water content, expressed as the fraction of total available soil water between field capacity and wilting point that is readily available for crop transpiration and characterizes a soil moisture condition in which crop transpiration is not limited by any flow restrictions in the root zone. Above more than 100% critical depletion of soil moisture different yield reduction was recorded [1].

Water production funtion

The effect of water stress on yield is quantifield by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield response factor (K_y).

$$1 - \frac{Y_a}{Y_{max}} = K_y \left(1 - \frac{ET_a}{ET_m}\right)$$

Where, $1–Y_a / Y_{max}$ = The fractional yield reduction as a result of the decrease in evaporation rate ((1 – ET_a / ET_m) and K_y = Yield response factor.

Results and Discussion

Simulated yield reduction using CROPWAT model under different irrigation criteria

The reduction in ET_c yield and cumulative yield reduction under I_1 to I_5 irrigation treatment was simulated by CROPWAT model phase wise (Table 1). Results showed that 3.6, 20, 10.1, 4.1 and 3.8 mm seasonal ET reduction was recorded under I_1, I_2, I_3, I_4 and I_5 treatments respectively. Highest ET_c reduction (20 mm) was recorded under I_2 (0.4 IW / CPE) treatment and lowest (3.6 mm) under I_1 treatment. Similarly 3.6, 20, 10.1, 4.1 and 3.8% cumulative yield reduction was simulated by model for I_1, I_2, I_3, I_4 and I_5 treatment respectively. Lowest yield reduction (3.6%) was observed under I_1 treatment and highest reduction (20%) under I_2 treatment. Nearly 26, 8.5, 30.5 and 7.2 mm reduction in ET_c (mm) at initial, development, mid and late stage of wheat which affected negatively with poor yield as compared to other treatment respectively.

Crop water production function (K_y)

Crop water production function (K_y) as presented in

Table 2 indicated that linear relationship between the decrease in relative water consumption and the decrease in relative yield. It showed the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption. The lower value of K_y as obtained under I_1, I_5 suggesting less yield reduction, while higher value in I_2, I_3 and I_4 showed moisture stress caused significant yield reduction. These results suggest that treatment I_1 and I_5 found superior as compared to rest of the treatment as far as yield is concerned. The I_1 treatment's yield was considered as base yield for computation of K_y for different treatment accordance with percentage yield reduction under respective treatment.

Irrigation criteria of irrigated
critical depletion

Using the irrigation criteria irrigate at critical depletion (Table 3) 100% critical depletion was given as input in which the model simulation gave 0% yield reduction. This showed that upto 100% critical depletion of soil moisture there was any reduction in wheat yield. Above more than 100% critical depletion of soil moisture different yield reduction was recorded.

Irrigation criteria of irrigate at
above critical depletion

Result showed that yield was not reduced at 100% soil moisture depletion. But at 110, 120, 130 and 140% critical depletion yield reduction was recorded (Table 4). As the percent of critical depletion increases linearly increase was found in yield reduction. At 110% critical depletion yield reduction was found only 1% because of lower reduction in ETc in all the phase. At 120, 130 and 140% critical depletion of soil moisture cumulative yield reduction was 4.5, 12.8 and 19.6 with reduction in ET_c 3.8, 11.3 and 26% in initial stage respectively. In all the critical level (110, 120, 130 and 140%) reduction in ET_c was found more under mid and late development stage of wheat. This result clearly indicated that reproductive and maturity phase of wheat are more sensitive to moisture stress than initial and development stage of wheat.

Crop water production
fiunction (K_y)

The water production function (K_y) for fixed depletion (110 to 140%) was computed and presented in Table 5. Results revealed that yield, ET_a / ET_m, Y_a / Y_m was linearly decreased as depletion of moisture increased and K_y values increased. The low K_y (0.078) for 100% and highest K_y (0.672) for 150% depletion was observed. The I_1 treatment's yield was considered as base yield for computation of K_y for different treatment accordance with percentage yield reduction under respective treatment.

Irrigation criteria of irrigate
at fixed depletion

The phase wise yield reduction under different irrigation criteria at fixed depletion (mm) was simulated for 100 to 150 mm with 10 mm interval and presented in Table 6. As the sandy loam soil can held 100 to 150 mm of water per meter depth of soil and hence, 100 to 150 mm fixed depletion was assessed upto 50 mm depletion. The cumulative yield reduction (%) for fixed depletion of 100 to 150 mm was 6.4, 7.9, 9.9, 13.1, 17 and 22.3% respectively. Relationship was found linear. Further analysis suggested that under all the fixed depletion level > 100 mm reduction in ETc was recorded higher under initial and development stage of the wheat crop as compared to other stages. This clearly suggested that there two stages were more sensitive to moisture and finally on yield.

Crop water production
function (K_y)

The water production function (K_y) for fixed depletion (100 to 150 mm) was computed and presented in Table 7. Result clearly showed that yield, ET_a / ET_m, Y_a / Y_m were linearly decreased as depletion of moisture increased and K_y value was increased. The low Ky (0.363) for 100 mm and highest K_y (0.706) for 150 mm was observed.

Irrigation criteria of irrigate at ET crop per stage

For assessment phase wise unit reduction in ET crop and its consequent effect on different growth stage on final yield, the ET reduction per stage (5 to 50%) was simulated and results are presented in Table 8. Results showed that cumulative yield reduction was propositionally related with propertied ET crop reduction per stage. Under lower reduction in ET crop yield reduction was found lower and vice versa. Phasewise ET_c reduction was also found vary under different ET_c reduction. At 5, 10, 30, 45 and 50% ET_c reduction per stage severely affected on mid and late stage causing higher ET reduction as compared to other stage of crop. Under 25, 35 and 40% ET reduction per stage adversely affected on ET reduction owing mid and late stage of wheat as compared to other stage of crop. Under all the ET crop reduction per stage, it was revealed that mid stage was found most critical for moisture. Under scarcity of water ET_c was found to decrease and negatively affect final crop yield. The percent reduction in ET_c (5, 10, 25, 30, 35, 40, 45 and 50%) was simulated phase wise of wheat crop. The minimum yield reduction occurred at 5% (4.1%) ET_c whereas the maximum at 50% (47.5%) in wheat crop.

Crop water production function (K_y)

The water production function (K_y) for fixed depletion (5 to 50%) was computed and presented in Table 9. Results obtained that yield. (ET_a / ET_m, Y_a / Y_m) and crop water production function (K_y) are linearly decreased as depletion of moisture increased. The low K_y (0.248) for 5% and highest K_y (0.890) for 50% was observed. The I_1 treatment's yield was considered as base yield for computation of K_y for different treatments accordance with percentage yield reduction under respective treatment.

Conclusion

Following conclusions have been drawn. Highest ET_c reduction (20 mm) was obtained under I_2 (0.4 IW / CPE) treatment and lowest (3.6 mm) under I_1 treatment. Similarly 3.6, 20, 10.1, 4.1 and 3.8% cumulative yield reduction was simulated by model for I_1, I_2, I_3, I_4 and I_5 treatment respectively. Lowest yield reduction (3.6%) was obtained under I_1 treatment and highest reduction (20%) under I_2 treatment. Nearly 26, 8.5, 30.5 and 7.2 mm reduction in ET_c (mm) at initial, development, mid and late stage of wheat, the CROPWAT simulated lowest ET_c and yield reduction under I_1 treatment (3.6%) and lowest K_y (0.0) value as compared to other treatment under fixed irrigation interval. The low K_y (0.248) for 5% and highest K_y (0.890) for 50% was obtained, the percent reduction in ET_c (5, 10, 25, 30, 35, 40, 45 and 50%) was simulated phase wise of wheat crop, low K_y (0.078) for 100% and highest K_y (0.672) for 150% depletion was observed, 110% critical depletion yield reduction was found only 1% lower reduction in ET_c in all the phase. At 120, 130 and 140% critical depletion of soil moisture cumulative yield reduction was 4.5, 12.8 and 19.6 with reduction in ET_c 3.8, 11.3 and 26% in initial stage respectively. In all the critical level (110, 120, 130 and 140% reduction in ET_c was found more under mid and late development stage of wheat. This result clearly showed that reproductive and maturity phase of wheat are more sensitive to moisture stress than initial and development stage of wheat.

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