Actual and predicted evapotranspiration along with groundwater contribution for wheat (*Triticum aestivum*) crop

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Abstract: This experiment aimed to determine the crop evapotranspiration (ET_c) and groundwater input in total water used by wheat (*Triticum aestivum*) crop and to use the CROPWAT model to predict the crop ETc. To estimate the on-field ET_c and groundwater contribution, the combining lysimeter technique was used. The water levels below the soil surface were kept at 1.60, 2.20, and 2.80 m and each water table depth was replicated three times. A field experiment was conducted under silt loam (SL) and silty-clay loam (SCL) soil conditions. The climatic parameters and water balance components were recorded accordingly. The on-field ET_c was compared with the predicted ET_c by CROPWAT model. Under SL soil, the observed ET_c was 442, 427 and 401 mm and under SCL soil conditions it was observed as 419, 402 and 389 mm at the water table depth of 1.60, 2.20, and 2.80 m, respectively. The ET_c was reduced with an increase in water level below the surface. The groundwater contribution under SL and SCL soil was observed as 50%, 41%, and 30% and 43%, 34%, and 24%, at 1.60, 2.20 and 2.80 m water table depth, respectively. The predicted ET_c by CROPWAT model for SL and SCL soil conditions was 428.8 and 410.7 mm, respectively. The projected ET_c was equal to the average ET_c observed under lysimeter experiment. Thus, the use of CROPWAT model is recommended to overcome waterlogging and salinity problems and to conserve water resources. Considering lysimeter results, the irrigation applications must be revised for shallow water table levels due to adequate contribution of groundwater.

Keywords: water conservation, irrigation amount, groundwater, crop evapotranspiration

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1 Introduction

Globally, water is considered as a dominant driver of agricultural productions and plays a vital role in completing a major share of the world's cereal demand (Mursalova et al., 2015; Shekari et al., 2015). Rapid growth in population has increased the demand of food production throughout the world (Gul et al., 2018). Higher water consumption rate by domestic and industrial sectors has put forth a substantial pressure on irrigation water accessibility and agriculture water use (Liu et al., 2007; Guler, 2010). The shortage in irrigation water supply confines the crop productivity and increases

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stress in crop water availability which directly reduce the crop yield (Ghassemi-Golezani et al., 2015; Ghane et al., 2009; Wang et al., 2009).

Wheat (*Triticum aestivum*) is a major crop of Pakistan which is cultivated on about 9.2 M ha^{-1} land and the total production of wheat crop is 26 Mt. Being Pakistan an agriculture country, the yield is still 15% less than the developed countries (Gul et al., 2018). During 2013-14 the recorded average yield of wheat crop was 2.8 t ha^{-1} but the developed countries were obtaining yields around 3.3 t ha^{-1} (Rao et al., 2016; GoP, 2014). This decrease in crop yield could be due to the over or lesser irrigation amounts (Gul et al., 2018). On the other side, the alarming rate of increase in population has increased the water demand for all the major sectors, viz, agriculture, domestic, and industrial. Pakistan is still enjoying one of the largest surface irrigation systems, but the water losses from field channels, mainly canals, and over irrigation events has amplified water logging problems (Ashraf, 2016).

Waterlogging problems are producing major threats for agriculture sector at Lower Indus Basin. Almost 24% of gross command area (5.74 M ha^{-1}) of Sindh Province has water table less than 3/2 m and 55% area has water table level between 3/2 to 3 m beneath the soil surface (Bhutta and Sufi, 2004). The awareness of irrigating the lands according to the crop water requirements is lacking between the local famers. Over irrigating practice between the farmers has been observed many times with the intents that the crop yield could be increased by over watering (Rao et al., 2016). Supplementary irrigations not only yield low water productivity (WP) but also percolate micro-nutrients out of the crop root zone, thus decreases the crop yield. The irrigation water could not efficiently utilize without knowing the actual water requirement of the crops (Ashraf et al., 2001). The water requirement of a crop depends upon soil texture, climatic conditions, water table level, crop grown, and somehow on practices performed during crop cultivation (Gul et al., 2018; Dahri, et al., 2021).

Plants can easily uptake water from the storage available at shallow groundwater level. A momentous amount of groundwater contribution in crop water use has been evident by many researchers. They concluded that, under low water table levels the irrigation applications must be ended earlier (Soppe and Ayars, 2003; Stampfli and Madramootoo, 2006; Babajimopoulos et al., 2007). About 70% water requirement of wheat crop could be accomplished from groundwater if the water-table depth is 0.5 m, and only 100 mm pre-sowing water application is adequate for achieving optimum crop yield (Rao et al., 2016; Javaid and Solangi, 1987).

In a copious range of climatic conditions, the estimation of water requirement of a crop could be attained using computer-based decision reinforced models. The modern computer-based crop-water models such as CROPWAT and AQUA-CROP can be used for exploring the supplemental irrigation management approaches (Hurst et al, 2004; Dahri, et al., 2021). For every semi-arid climatic zone, the knowledge of actual crop water requirement is necessary for sustainable water consumption, improved irrigation practices and proficient use of water. CROPWAT model also predicts the effective rainfall if long meteorological data is available. The approaches of this model are supportably concluded by many researchers (Nazeer, 2009; Bouraima et al., 2015; Luo and Sophocleous, 2010). for the revision of irrigation applications according to the agro-climatic conditions. CROPWAT enables the estimation of crop evapotranspiration, reference evapotranspiration, irrigation schedule and crop water requirements with diverse cropping arrangements for irrigation planning (Nazeer, 2009). The FAO CROPWAT model incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate, crop and soil conditions (Bouraima et al., 2015; Dahri, et al., 2021). To design the diverse management practices such as waterlogging prevention and salinity control, the use of CROPWAT model is recommended based on its optimum accuracy (Dahri, et al., 2021).

Keeping in view of the aforementioned facts, this study was conducted to estimate and compare the on-field and CROPWAT's predicted evapotranspiration of wheat crop, as well as to analyze the groundwater input in total water consumed by the crop.

2 Materials and methods

2.1 Description of the experiment

CROPWAT model requires soil, crop, and climate data for crop water estimations but not information about groundwater. However, under lysimeter study different water table depths were maintained to check out the groundwater contribution on the crop.

2.1.1 Experimental location

The experiment was conducted at the research field of Sindh Agriculture University (SAU) Tandojam, Pakistan, from November 2017 to March 2018. The experimental site is located at 25.424843^0 N and 68.540755^0 E and at an average altitude of 12.8 m above the mean sea level. The locally available variety of wheat crop named TD-1 was grown. Figure 1 shows the layout and location map of the experimental site.

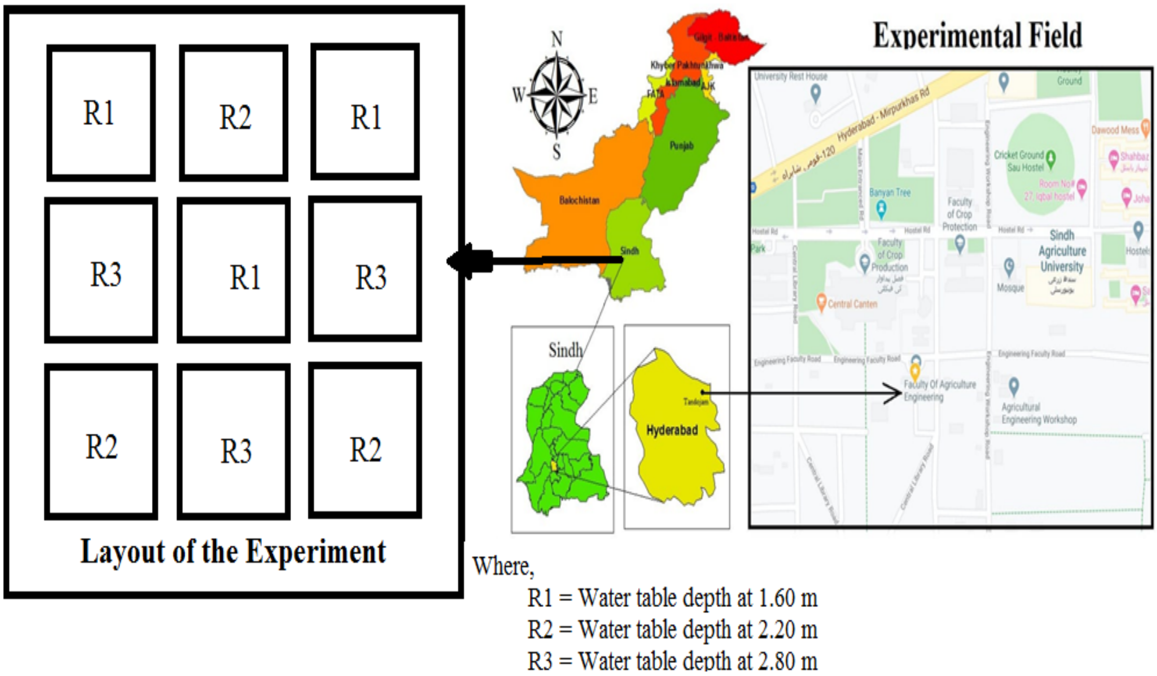

Figure 1 Location map and layout map of the experimental site

2.1.2 Data

The data used in this study included lysimeter data, ten years weather data, and soil physical characteristics. The climatic data was obtained from the nearest observatory installed at Drainage and Reclamation Institute of Pakistan (DRIP) Tandojam, which is approximately 1.5 km away from the experimental site. The level of water table was kept as 1.60 m, 2.20 m, and 2.80 m to the ground surface. Each water table treatment was replicated three times. The experiment was conducted in completely randomized block design (RCBD) for different water table treatments.

2.1.3 Lysimeter conditions

The installed lysimeter at FAE was RCC (Reinforced Cement Concrete) made. The water leakage from lysimeters was restricted using bitumen coating from all the four sides and the bottom. The size of each chamber of the lysimeter was 15.63 m^3. For facilitate the required drainage limits the chambers were filled with gravel, river sand, alter screens, and non-calcareous sprawls and drainage outlet. The levels of water table were maintained using Mariotte bottles. The drainage effluent (surplus water) of the lysimeters was allowed to flow into the graduated percolation bottles and measured accordingly. To check the maintenance of desired water tables, each lysimeter was provided with piezometers. Thus, the total water consumed by the crop was measured each 24 h.

Table 1 Physical characteristics of the two soils used in the experiment.

Soil No.	Soil Particle Proportion Sand (%)	Silt (%)	Clay (%)	Soil Texture	Dry Bulk Density (kg m^{-3})	Hydraulic Conductivity (m day^{-1})
1	23	53	24	SL	1370	0.144
2	11	53	36	SCL	1290	0.156

Note: SL = Silty Loam, and SCL = Silty Clay Loam

2.1.4 Soil

The lysimeter chambers were filled with two commonly available soils around the experimental site, namely silt loam (SL) and silty clay loam (SCL) soils. Table 1 shows the physical characteristics of the soils used in the experiment.

2.1.5 Crop evapotranspiration (ET_c)

The pre-installed piezometers were used to check out the change in water table depth on daily basis every 24 h. The sum of decrease or increase in water table throughout the crop season was considered as total groundwater contribution to crop water requirement. Equation 1 was used to estimate the actual evapotranspiration (synonymously discussed as Consumptive Use) or crop water requirement (Rao et al., 2016, Gul et al., 2018; Allen et al., 1998).

$$ET_c = I + S + R - D \pm SMD \quad (1)$$

Where;

ET_c = Crop evapotranspiration (mm)

I = Surface irrigation (mm)

S = Contribution of groundwater (mm)

R = Rainfall (mm)

D = Drainage effluent (mm)

SMD = Soil moisture difference (mm)

2.1.6 Reference evapotranspiration (ET_O)

There exist several ETo methods (Shaikh et al., 2016; Shaikh et al., 2018). In this study for the estimation of reference evapotranspiration (ET_O) of wheat crop, the modified form of Penman equation (Equation 2) was used. The value of temperature factor (W) and wind function [f (U)] was obtained from Doorenbos and Pruitt (1977),

$$ET_o = W\,x\,R_n + (1 - W) - f\,(U) - (e_a - e_d) \quad (2)$$

Where;

ET_O= Reference evapotranspiration (mm day^{-1})

W= Temperature factor (dimensionless)

R_n= Net radiation in equivalent evaporation (mm day^{-1})

$f\,(U)$ = Wind function (dimensionless)

$(e_a - e_d)$ = Difference among the saturation vapor pressure (at mean air temperature) and mean actual vapor pressure (mbar).

2.1.7 Crop coefficient (K_c)

The crop coefficient was also calculated on daily basis using the estimated reference evapotranspiration and crop evapotranspiration values. The crop coefficient (K_c) of the sesame crop was calculated using Equation 3 (Allen et al., 1998).

$$K_c = \frac{ETc}{ETo} \quad (3)$$

Where;

K_c= Crop coefficient (dimensionless)

ET_c= Crop evapotranspiration (mm)

ET_o= Reference evapotranspiration (mm)

2.1.8 Measurement of water balance components

The controlled lysimeters were used to estimate the major water balance components which include surface irrigation (I), drainage effluent (D), and soil moisture difference (SMD). Contribution through natural precipitation or rainfall (R) was measured using pre-installed rain gauge. To fill the Mariotte bottles a pipeline was fixed from lysimeter chambers to the bottles. Ground water contribution (S) from Mariotte bottles to rise or maintain the water table depth was considered as groundwater contribution. The drained-out water from chambers was collected in percolation bottles (Jerry canes) and recorded, which is called drainage effluent (D). The difference of pre and post experiment soil moisture was considered as SMD. Hence, all the water inputs (I, S and R) and outputs (D) and SMD, helped to estimate the crop water requirements (Rao et al., 2016; Luo and Sophocleous, 2010; Soppe and Ayars, 2003; and Durner et al., 2008).

2.1.9 Crop yield under lysimeter experiment

To estimate the yield in a kg ha^{-1}, the observed yield under each lysimeter chamber (of 6.25 m^2 in size) was determined for each water table depth, separately. The obtained yield was averaged from all three replications of each treatment.

2.1.10 Statistical analysis

The standard t-test was used to check out the significant or non-significant difference among the yield observed under studied water table treatments at 95% (α = 0.05) confidence interval.

2.1 CROPWAT model

2.2.1 CROPWAT model inputs and outputs

CROPWAT model provides a complete package of irrigation amount and irrigation schedule, according to the crop growth stage. The observer can use the simulated output of the model if accurate input data has been incorporated. The CROPWAT model uses an integrated version of standard equation which is used to estimate the crop evapotranspiration. The modified form of Penman-Monteith method expressed in Equation 4 is integrated in the CROPWAT model of version 8.0 (Allen et al., 1998; Bouraima et al., 2015)

$$ET_O = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} U_2\,(e_a - e_d)}{\Delta + \gamma\,(1 + 0.34 U_2)} \quad (4)$$

Where;

ET_O = 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 speed at 2 m height (m s^{-1})

e_s = Saturation vapour pressure (kPa)

e_a = Actual vapour pressure (kPa)

e_s-e_a = Saturation vapour pressure deficit (kPa)

Δ = Slope vapour pressure curve (kPa °C^{-1})

γ = Psychrometric constant (kPa °C^{-1})

2.2.2 Climate, soil, and crop data incorporated in CROPWAT model

The very first input section of CROPWAT asks to add climate data. Then the rainfall, crop, and soil data are required to estimate crop water requirements. Table 2 shows the average climate data of ten years (2007 to 2016) which was incorporated in CROPWAT model. The average rainfall data was incorporated accordingly to simulate the effective rainfall. Table 3 and Table 4 show the soil and crop data, respectively, which was incorporated in the model. The obtained soil and crop data under lysimeter experiment was first verified from (Doorenbos and Pruitt 1975; Allen et al.,1998) and subsequent values were used in the model. The crop characteristics such as planting day, K_c values, growth stage, and rooting depth were given. In soil input section soil characteristics, the moisture available in the soil (mm m^{-1}), rain infiltration rate (mm day^{-1}), rooting depth (cm) and preliminary soil moisture depletion (%) were also incorporated, accordingly. Thereafter, the model was simulated for predicting the required irrigation management options.

Table 2 Average weather data of ten years incorporated in CROPWAT model

Month	Average Daily Temperature (C^o)		Average Relative Humidity (%)	Average Wind Velocity (km day^{-1})	Average Sunshine Hours (h)	Average Rain Fall (mm)
	Min.	Max.				
January	10.03	23.50	66	39.56	8	1.46
February	11.85	26.14	62	35.25	9	0.60
March	17.19	33.41	59	50.04	9	0.00
April	22.58	37.55	53	100.48	9	6.45
May	27.43	40.71	59	218.54	9	0.00
June	28.69	38.45	61	223.15	8	16.39
July	28.71	36.13	69	204.55	7	35.60
August	25.70	33.32	74	159.13	7	76.32
September	26.41	34.72	72	108.78	8	49.21
October	21.99	35.18	66	37.47	9	1.28
November	15.80	30.84	60	23.09	9	0.59
December	11.33	23.83	63	55.50	8	7.79

Table 3 Soil data incorporated in CROPWAT model

Soil No.	Soil Texture	Available Water (mm m^{-1})	Infiltration Rate (mm day^{-1})
01	Silt Loam	150-230	264
02	Silt Clay Loam	130-160	235

Table 4 Crop data used in CROPWAT model

Crop Coefficient (K_c)			Yield Response Factor (K_y)				Rooting Depth (m)	Depletion Fraction (P)
I	M	E	I	D	M	L		
0.65	1.45	0.80	0.20	0.60	0.50	0.50	1.50 – 1.80	0.55

Note: I = Initial, M = Mid, E = End, D = Development, and L = Late

3 Results and discussion

3.1 ET_c of wheat crop and groundwater contribution (mm)

Under the studied water table depths and soil textures, the overall ET_c of wheat crop ranged between 389 mm to 442 mm. Table 5 shows the crop evapotranspiration observed under the water table depth of 1.60, 2.20 and 2.80 m, respectively. The SL resulted in greater evapotranspiration rate as compared to the CLS. The maximum ET_c was observed under 1.60 m depth whereas the minimum was observed under 2.80 m water table depth. The smaller water table depth had greater water contribution in total crop evapotranspiration. For SL, the groundwater contribution under the water table depth of 1.60, 2.20 and 2.80 m was observed as 50%, 41% and 30%, respectively. Under SCL, the groundwater input at 1.60, 2.20 and 2.80 m depth of water table, the ET_c was observed as 43%, 34% and 24%, respectively. Under increased water table depth, both ET_c and groundwater contribution decreased. The difference in ET_c was due to the difference in ground water contribution at different water table depths because the soils having shallow water levels have potential to pass groundwater to the plant rootzone more rapidly as compared to the deeper ones. The difference in ET_c value in SL and SCL soil was because of clay particles proportion. These results indicate that, the water requirement of wheat crop changed for each water table depth and soil texture. It is evident from groundwater input data of shallow water levels that the irrigation applications should be ended before the required depth because a substantial share in water supply is being produced through groundwater. The results were in quite agreement with the experiment conducted by Rao et al., (2016) and Gul et al., (2018). They concluded that the ET of crop relatively increases under the deeper water table depth conditions, whereas the irrigation practices mut be turned off before required level under shallow water table depths, due to sufficient ground water contribution.

Table 5 ET_c (mm) of wheat crop and groundwater (S) contribution (mm)

Month	Days	Silt loam (SL)						Silty-clay loam (SCL)					
		1.60 m		**2.20 m**		**2.80 m**		**1.60 m**		**2.20 m**		**2.80 m**	
		ET_c	**S**	**ET_c**	**S**	**ET_c**	**S**	**ET_c**	**S**	**ET_c**	**S**	**ET_c**	**S**
Nov	25	72	35	67	26	22	4	48	16	44	16	23	0
Dec	31	93	47	81	32	109	26	98	37	99	23	113	26
Jan	31	85	41	94	35	97	31	95	34	93	37	86	22
Feb	28	104	54	111	56	102	49	97	59	101	51	97	41
Mar	26	90	42	74	27	71	12	81	35	67	11	70	5
SMD	-	-3	-	1	-	3	-	2	-	0	-	2	-
Total	**141**	**442**	**219**	**427**	**176**	**401**	**122**	**419**	**181**	**402**	**138**	**389**	**94**

Note: ET_C = Crop Evapotranspiration, S = Ground water contribution, SMD = Soil moisture Difference before and after the experiment.

Generally, the crop evapotranspiration (ET_c) is higher in Lower Indus Basin as compared to the Upper Indus Basin due to the high temperature and wind speed in the Lower Indus Basin. The average ET_c under silt loam and silty clay loam soil in the present study was observed as 423 and 403 mm, respectively. This is because the adequate proportion of clay particles in SCL soil produced wider surface area which resulted in greater water retention capacity of the soil, which ultimately ensued lower ET_c then SL soil. The high ET_c in SL soil might be due to the more evaporation from the soil surface and less transpiration. The mean monthly temperature and reference evapotranspiration (ET_o) during the study period is shown in Figure 2. The lowest reference evapotranspiration was observed in December, whereas it was maximum in March. The steady increase in temperature resulted gradual increase in both ET_o and ET_c. The results are strongly supported by the findings of Javaid and Solangi (1987) and Gul et al., (2018). The output of their studies is proofing that the soils having more clay particles may have potential to reduce the water requirements for crop.

3.2 Crop coefficient (K_c)

Crop coefficient plays a dominant character in fining the total water requirement of experimental crop. Figure 3 shows the monthly crop coefficient value of wheat crop observed under experimental water table treatments. In the present study, the crop coefficient was found to be highest in the month of December (above 1.20). This is due to relatively higher evaporation rates from more exposed area of the soil surface. The minimum Kc value (0.36) was observed in November. The K_c values are within the range of crop coefficient of wheat crop observed under similar climate and soil conditions. The deeper water table depth has produced higher crop coefficients compared to the shallow depth, due to the lower contribution of groundwater which eventually increased the ET_c under 2.20 m and 2.80 m WTD. This difference in K_c value is due to the change in crop evapotranspiration and reference evapotranspiration at different stages at different water levels. The difference in K_c value for each month is mainly due to the developing-cum mature stage of the crop. The outcomes of Rao et al., (2016) are supporting the findings of this study.

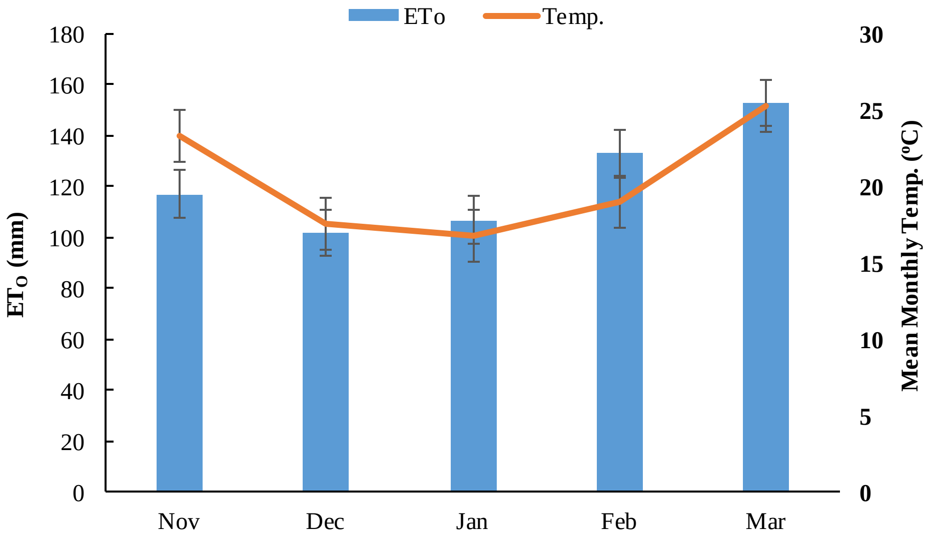

Figure 2 Average and standard error bars for reference evapotranspiration (ET_o) and mean monthly temperature (T) during the study period

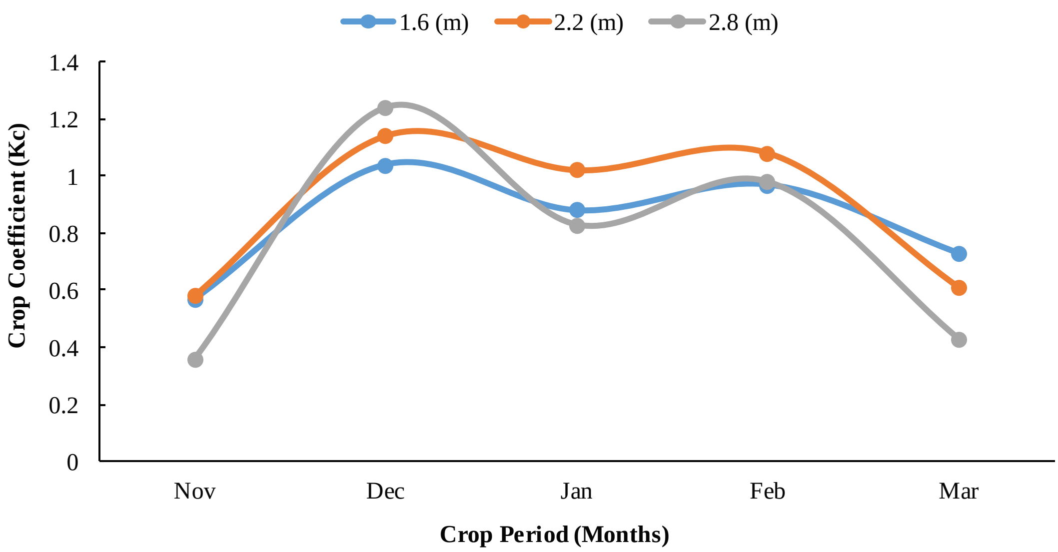

Figure 3 Monthly crop coefficient (K_c) of wheat crop observed under different water table depths.

3.3 Yield of wheat crop

The yield of wheat was higher under shallow water table depth (1.60 m) as compared to deeper depths (2.80 m). This is because, the plants were least exposed to moisture stress under the shallow water table depth, as shown in Table 6.

The crop yield obtained under 1.60 m of water table depth was 10% more, when compared to the yield achieved under the water table depth (WTD) of 2.20 and 2.80 m. The same increasing trend in crop yield was observed under the WTD of 2.20 m compared to 2.80 m. The crop produced higher yield within shallow WTD as compared to deeper WTD. This is because the moisture stress was controlled by monitoring the water table depth and early stopping of irrigation application, in shallow water level conditions. The results are in quite agreement with the findings reported by the Rao et al., (2016) and Javaid and Solangi (1987).

Table 6 Yield of Wheat (kg ha^{-1}) under different water table depths

Replication	Yield (kg ha^{-1}) Water Table Depth 1.60 m	2.20 m	2.80 m
R_1	2620	2710	2615
R_2	2795	2570	2635
R_3	2550	2610	2540
Average	2655	2630	2595

Table 7 Statistical analysis of the yield of wheat crop

Treatments Compared	Mean Yield (kg ha^{-1})	P-Value	Significance Level
1.60 & 2.20	2655 & 2630	0.7852	Non-Significant
1.60 & 2.80	2655 & 2595	0.7852	Non-Significant
2.20 & 2.80	2630 & 2595	0.7852	Non-Significant

The yield difference under different water table levels was non-significant at 5% significance level (P value was greater than 0.05), as shown in Table 7. The inconsistent change in crop yield caused non-significant difference in the yield. Under shallow water levels, the yield was optimum because the plants were least exposed to moisture stress. However, the increased moisture stress in 2.20 m and 2.80 m WTD reduced the crop yield. The overall yield of the crop is low when compared to the average wheat yield recorded in the Sindh Province, which was 3500 kg ha^{-1} in 2013 (Rao et al., 2016; GoP, 2014). It is therefore necessary conducting the experiment with the latest varieties of wheat being planted in the province. Yield of crop was analyzed statistically, and results are shown in Table 7. The results are strongly supported by Rao et al., (2016) and Gul et al., (2018).

3.4 Outputs of CROPWAT model

3.4.1 ET_c of wheat crop projected by CROPWAT model

The simulated crop water requirement (ET_c) of wheat crop under silt loam and silty-clay loam soil conditions are given in Tables 8 and 9, respectively. Under silt loam soil conditions, the predicted ET_c of wheat crop by CROPWAT model was 428.8 mm. The model divided the crop season into four stages, i.e. initial stage, development stage, mid stage, and late stage. The effective rainfall during whole crop season was simulated as 10.6 mm. In the initial stage of growth, the crop needed minimum quantity of water (24 mm decade^{-1}) in the November and the simulated ET_c was recorded as 21.5 mm decade^{-1}. The highest crop water requirement (ET_c) was simulated as 121.7 mm in the mid stage of growth which was 28.40% of total water requirement of wheat crop throughout the crop season. The results displayed in Table 8 reveal that the ET_c was greater in the middle stage of crop season which consists five decades (two from January and three from February) with total ET_c of 193.3 mm. In comparison with Table 5 it is clear that the ET_c under both studies is found greater in February. CROPWAT model does not require ground water data but the results are showing that the model can compute crop water requirements accurately. The outputs of CROPWAT model are comparatively the same as recorded in field. This is because the input values of climate, crop and soil are same as they were recorded. The climate condition during the experiment was within the limits of average climate of past ten years. The simulation results of CROPWAT model are in agreement with the results discussed by Bouraima et al., (2015) and Nazeer (2009).

Table 8 Predicted ET_c of wheat crop using CROPWAT model (for silt loam soil)

Month	Decade	Stage	Kc coeff	ET_c mm day^{-1}	ET_c mm dec^{-1}	Eff rain mm dec^{-1}	Irr. Req. mm dec^{-1}
Nov	1		0.5	1.57	7.8	0.1	7.8
Nov	2	Initial	0.5	1.37	13.7	0	13.7
Nov	3		0.5	1.28	12.8	0.6	12.2
Dec	1		0.63	1.48	14.8	2.2	12.6
Dec	2	Development	0.85	1.85	18.5	3.2	15.3
Dec	3		1.09	2.32	25.5	2.3	23.2
Jan	1		1.33	2.76	27.6	1.1	26.6
Jan	2	Middle	1.56	3.16	31.6	0.3	31.3
Jan	3		1.64	3.64	40	0.3	39.8

Feb	1		1.64	3.95	39.5	0.3	39.2
Feb	2		1.64	4.26	42.6	0.2	42.4
Feb	3		1.64	4.94	39.6	0.1	39.4
Mar	1		1.46	4.98	49.8	0	49.8
Mar	2	Late	1.12	4.28	42.8	0	42.8
Mar	3		0.84	3.67	22	0.1	22
		Total			428.8	10.6	418.2

Table 9 Predicted ETc of wheat crop using CROPWAT model (for silty-clay loam soil)

Month	Decade	Stage	Kc coeff	ETc mm day^{-1}	ETc mm dec^{-1}	Eff rain mm dec^{-1}	Irr. Req. mm dec^{-1}
Nov	1		0.65	2.04	12.3	0.1	12.2
Nov	2	Initial	0.65	1.79	17.9	0	17.9
Nov	3		0.65	1.67	16.7	0.6	16.1
Dec	1		0.74	1.75	17.5	2.2	15.4
Dec	2	Development	0.91	1.97	19.7	3.2	16.5
Dec	3		1.08	2.29	25.2	2.3	23
Jan	1		1.25	2.61	26.1	1.1	25
Jan	2		1.31	2.67	26.7	0.3	26.4
Jan	3	Middle	1.31	2.92	32.1	0.3	31.9
Feb	1		1.31	3.17	31.7	0.3	31.4
Feb	2		1.31	3.42	34.2	0.2	34
Feb	3		1.31	3.96	31.7	0.1	31.6
Mar	1		1.21	4.17	41.7	0	41.7
Mar	2	Late	1.04	3.98	39.8	0	39.8
Mar	3		0.86	3.74	37.4	0.1	37.3
		Total			410.7	10.6	400.1

Results illustrated in Table 9 show the simulated crop coefficient (Kc), crop evapotranspiration (ET_c), and the irrigation requirement for silty-clay loam soil. The predicted K_c values were within the range of observed K_c values. The total ET_c projected by CROPWAT model was 410.7 mm and the observed crop evapotranspiration values under applied treatments of water table depths are ranging between 389 mm to 419 mm. For ET_c, the RMSE value for SL and SCL soil was 0.09472 and 0.08314 mm, respectively. The RMSE value was close to zero, which indicates optimum output of the model. The outcomes of CROPWAT model were within the upper and lower limits of the results achieved in the lysimeter experiment. Furthermore, the same crop coefficient values indicate an optimum simulation accuracy of CROPWAT. The predicting crop stages further shows that the ET_c observed in different months in lysimeter experiment are favoring the outcomes of CROPWAT model. The accuracy of CROPWAT model is witnessed by Bouraima et al., (2015) and Nazeer (2009). In which they concluded that, if the input data is incorporated accurately, the model can forecast the crop water requirement results more efficiently.

3.4.2 Predicted yield reduction percentage

The over-watering or deficit irrigation applications causes a substantial loss in crop yield. Therefore, the simulated results are considered optimum only when there is no loss of yield is predicted. Table 10 shows the yield reduction response projected by CROPWAT model. The projected results for both soil types are at 0.0% yield reduction response, which indicates that, if the simulated results are applied accordingly there will be no any loss of crop yield due to the water requirement applications.

Table 10 Yield reduction response projected by CROPWAT model

Parameters	Crop stage				Overall season
	Initial	Development	Mid	End	
Reduction in ET_c	0.00	0.00	0.00	0.00	0.00%
Yield Response Factor (YRF)	0.20	0.60	0.50	0.50	0.55%
Yield Reduction	0.00	0.00	0.00	0.00	0.00%
Cumulative yield reduction	0.00	0.00	0.00	0.00	0.00%

The results further demonstrate that, the yield response factor is maximum in development stage which is gradually decreased in mid and end stages of the crop. The minimum yield response factor was predicted for initial stage. However, the overall YRF for entire crop season was predicted as 0.55. The yield reduction problem due to water deficit or over watering applications could be handled by implementing the irrigation schedule generated by CROPWAT model. To acquire optimum crop yield under different soils and climate patterns, the model can serve as a key source for revising or estimating the actual crop water needs. The results are supported by Dahri, et al., (2021); Bouraima et al., (2015) and Nazeer (2009).

4 Conclusions

The wheat crop being a major consumer of irrigation water resources needs high attention of proper irrigation applications. The CROPWAT's projected crop evapotranspiration (ET_c) of wheat crop is virtually same as observed through lysimeter technique. Under silt loam (SL) and silty-clay loam (SCL) soil conditions the predicted ET_c of wheat crop is 98.05% and 98.83% respectively same, as observed experimentally. The CROPWAT has no provision to estimate groundwater contribution hence it can be used to estimate the water requirement of a crop only. Under the studied water table depths of 1.60, 2.20 and 2.80 m, the average groundwater contribution in SL and SCL soils was 40% and 34%, respectively. On an average of both soil types, the shallow groundwater level (1.60 m) produced 47% input of the total water used by the crop. This means that irrigation applications should be ended earlier to overcome the soil salinity and waterlogging problems. Thus, on the basis of results drawn from this study, it is clinched that the water requirement of wheat crop could be obtained through CROPWAT model and the simulated results could be implemented, accordingly.

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