IJTA
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National Academy of Agricultural Science (NAAS)
Rating : 3. 03

Crop Water Requirement in Wheat (*Triticum Aestivum*) Under Variable Weather Condition in the Semi Arid Region of India

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Abstract: *Estimation of optimum water requirement for crop is essential for irrigation scheduling and water saving in an arid region for improving water use efficiency in the crop. A study was therefore conducted to estimate seasonal changes in evapotranspiration (ETc) for the wheat crop under variable weather conditions using single crop coefficient, dual crop coefficient and soil water balance equation at Research farm of ICAR-Indian Agricultural Research Institute, New Delhi during Rabi, 2012-13 and 2013-14. The reference crop evapotranspiration ET0, an important parameter in simulating the actual crop evapotranspiration (ETc), was estimated using FAO Penman–Monteith equation. The values suggested by FAO-56 were used for the crop coefficients after adjustment for the weather condition in the study area. The crop growth parameters were measured at different growth stages and seed yield were measured after harvest. Results showed that the total actual ETc was 390.6, 420.5 and 328.4 mm at the experimental site during crop growing period in first, second and third sown crop as estimated by single crop coefficient and 398.9, 450.5 and 436.8 mm as estimated by dual crop coefficient. Total value of reference crop evapotranspiration ET0 was 438, 469 and 451 mm respectively at the experimental site during crop growing period in first, second and third sown crop. This indicates that the weather conditions influence the water requirement in the crop. Since ETc calculated by dual crop coefficient consider the effect of soil evaporation and crop transpiration both therefore the value calculated by dual crop coefficient are more reliable as compared to single crop coefficient. Therefore ETc value calculated from the dual crop coefficient can be used for the irrigation scheduling in the crop for optimum use of irrigation water.*

Keywords: *Evapotranspiration; crop coefficient; wheat (*Triticum aestivum*); FAO-Penman monteith equation.*

INTRODUCTION

There is an enormous pressure on water resources due to long spell of drought in most parts. Therefore there is a need to conserve both the quantity and quality of water and appropriate strategies will have to be developed to avoid risk to future water supplies. One of the ways by which we can reduce the total water used for irrigation is to employ practices that improve crop yield per unit volume of water used *i.e.*, water use efficiency. Increased water use efficiency of crops was possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration and providing irrigation at critical growth stages. Wheat (*Triticum aestivum*) is one of the most important crops in the India, which contributes nearly one third of the total food grains production. Since the climate is very dry in the region, irrigation is necessary for obtaining reliable yields. Under normal conditions, four to six irrigations are recommended for optimum wheat production. The irrigation amount accounts for 80% of the freshwater resource usage.

However, considerable amounts of water diverted for irrigation are not effectively used for crop production (FAO, 1992). In recent years, the water storage has gradually decreased in this region mainly because of increasing annual irrigation. The

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dependence on water for food production has become a critical constraint to increasing food production. Therefore, the great challenge facing the agricultural sector is to produce more food from less water by increasing crop water productivity (Kijne *et al.*, 2003). To improve efficiency of water use in irrigated agriculture, a comprehensive knowledge of crop water require-ment, critical crop growth stages, and irrigation schedules for maximizing production are highly desirable along with the availability of adequate amount of water to meet the crop requirement (Yitaew and Brown, 1990; Kijne *et al.*, 2003; Yu-Lin Li., 2003). Crop water requirements vary substantially during the growing period due to variation in crop canopy and climatic conditions (Allen *et al.*, 1998), these are commonly estimated through the reference crop evapotranspiration (ET_0) and crop-coefficient (K_c). The reference crop evapotranspiration (ET_0) can be calculated using many methods (Zhang *et al.*, 2004, 2000, 1998; Kashyap and Panda, 2001; Moges *et al.*, 2003).

Among these, the FAO Penman Monteith method is recommended as the standard method. This method has been selected because it is physically based, and explicitly incorporates both physiological and aerodynamic parameters. The crop coefficient, commonly used to determine the actual water needs of a particular crop, is the ratio of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_0). It is a function of the climate, the soil, the particular crop and its varieties, the irrigation methods (Kijne *et al*, 2003). The single crop coefficient and dual crop coefficient methods are used to estimate the ET_c.

The single crop coefficient method is much simpler and more convenient than the dual crop coefficient method. Although some studies on the maize ET_c have been documented (Zuo and Xie, 1991), we are not aware of any studies on the wheat ET_c determined using crop coefficient method available for the study area. The crop coefficient is to be used in this study because accurate ET_c values are important for real time irrigation scheduling in the semi arid area. The main objective of this study is to determine water needs of wheat using the crop coefficient and to examination of evapotranspiration in wheat.

MATERIALS AND METHODS

Field experiments were conducted during 2012-13 to 2013-14 *Rabi* season at research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India. The climate of the station is semiarid with dry hot summers and cold winter. For creating variable weather conditions two varieties of wheat *viz.*, HD-2894 and HD-2851 were sown on 15th November, 1st December and 15th December. The crops were raised following the standard recommended agronomic practices with three replications in a randomized block design (RBD). Leaf area index (LAI), plant height, and weather parameters were taken. Number of days required to attain different stages were recorded. The leaf area index was measured using leaf area meter. The plant height was calculated by taking average of height of ten plants from each plot. The above measurements were taken at weekly intervals. The samples collected for estimating leaf area index were utilized for assessing the biomass production. Plants samples were oven dried at 65°C for 48 hours or more until constant weight is achieved in order to estimate the accumulation of dry matter in different plant parts.

The Both incoming and outgoing Photo-synthetically Active Radiation (PAR) values were measured at three heights *viz.* top, middle (50 percent canopy height) and bottom of crop throughout the season using line quantum sensor (LICOR-3000). Daily data of maximum and minimum temperatures, morning and evening relative humidity, rainfall, wind speed, bright sunshine hours and evaporation rates for season were obtained from the records of the meteorological observatory of the Division of Agricultural Physics, IARI, New Delhi, located adjacent to the experimental site. The daily weather data recorded during the crop growing season were noted for a detailed analysis. From the daily data collected, mean daily values during different weeks starting from the date of sowing were computed (in case of rainfall weekly total was computed) and analyzed to study the effect of weather factors on crop growth and development.

Potential evapotranspiration (ET_0) were estimated using FAO Penman–Monteith equation. The crop evapotranspiration were estimated using single crop coefficient equation and dual crop coefficient approach.

The reference evapotranspiration, ET_0, was calculated according to the FAO Penman-Montieth equation (Allen *et al.*, 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e^0 - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad ...(1)$$

Where ET_0 expressed in (mm day^1); R_n net radiation at crop surface (MJ m^{-2}hr^{-1}); G soil heat flux density (MJ m^{-2} day^{-1}); T 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); Δ the slope of the vapour pressure curve (kPa°C^{-1}) and ã is the psychrometric constant in (kPa^{o}C^{-1}).

Net radiation was calculated using the following formula:

$$Rn = (1 - r)(0.25 + 0.5n/N)S_0 - (0.9n/N + 0.1)(0.34 - 0.14\sqrt{ea})\,\sigma T^4 \quad ...(2)$$

where S_0 is the extraterrestrial radiation (MJ m^{-2} day^{-1}), e_a the vapor pressure (kPa), σ the Stefan-Boltzmann constant (4.903 × 10^{-9} MJ m^{-2} K^{-4} day^{-1}), T the air temperature (^{o}K), r the reflection coefficient (observed mean value, 0.24), n the number of hours of bright sunshine per day (h) and N the total day length.

Estimation of evapotranspiration was done using Single crop coefficient approach using following equation:

$$ET_c = K_c \times ET_0 \quad ...(3)$$

The crop evapotranspiration (ET_c) using dual crop coefficient where estimated using crop growth or evapotranspiration is as follows:

$$ET_c = (K_{cb} + K_e)\, ET_0 \quad ...(4)$$

where K_{cb} is the basal crop coefficient, K_e the soil evaporation.

In the absence of lysimetry, soil water balance method is a sound alternative for determining ET_c. The soil water balance method (Hanks and Ashcroft, 1980) determined the components (all expressed in mm) of the water balance equation for total volume defined by the soil profile of a given root zone depth and is written as :

$$ET_c = (P + I + U) - (R + D) - (\Delta S + \Delta V) \quad ...(5)$$

Where ET_c denotes estimated crop evapotranspiration (mm), P is precipitation (mm), I is irrigation (mm), D is deep percolation below the root zone (mm), R is runoff (mm) and ΔS is the change in profile soil moisture (mm), and ΔV is increment of water content in plants.

Runoff (R) was assumed to be negligible as the field plots were bunded (30 cm height) and no bund over flow occurred. ΔV is considered to be insignificant and was, therefore, ignored. The water table was below 15 m and therefore, capillary rise (U) was assumed to be zero. Change in soil moisture content (ΔS) was calculated for each period of crop growth from the initial and final soil moisture.

Water use efficiency was calculated using the following formula :

Root water uptake was computed from the depletion of soil moisture during the same period for 0-30 cm soil, assuming no drainage occurred as the soil moisture was very less during this period. Water use efficiency of the crop was calculated using the following formula:

Water use efficiency (WUE) :

$$\frac{\text{Biomass or yield produced (g m}^{-2}\text{)}}{\text{Amount of water used (cm)}} \quad ...(6)$$

RESULTS AND DISCUSSION

Net Radiation

The net daily radiation, the difference between the incoming net shortwave radiation and the outgoing net long wave radiation, is the fundamental variable for calculation of evapotranspiration. However, direct measurements were not available for the study area, and so equation 2 was used for estimating net radiation. The net radiation during crop growing period was sown in the (Figure 1).

Reference Evapotranspiration (ET_0)

The Penman-monteith equation was used for calculating the potential evapotranspiration. The value of estimated reference evapotranspiration estimated daily by Penman-monteith equation is given in Figure 2.

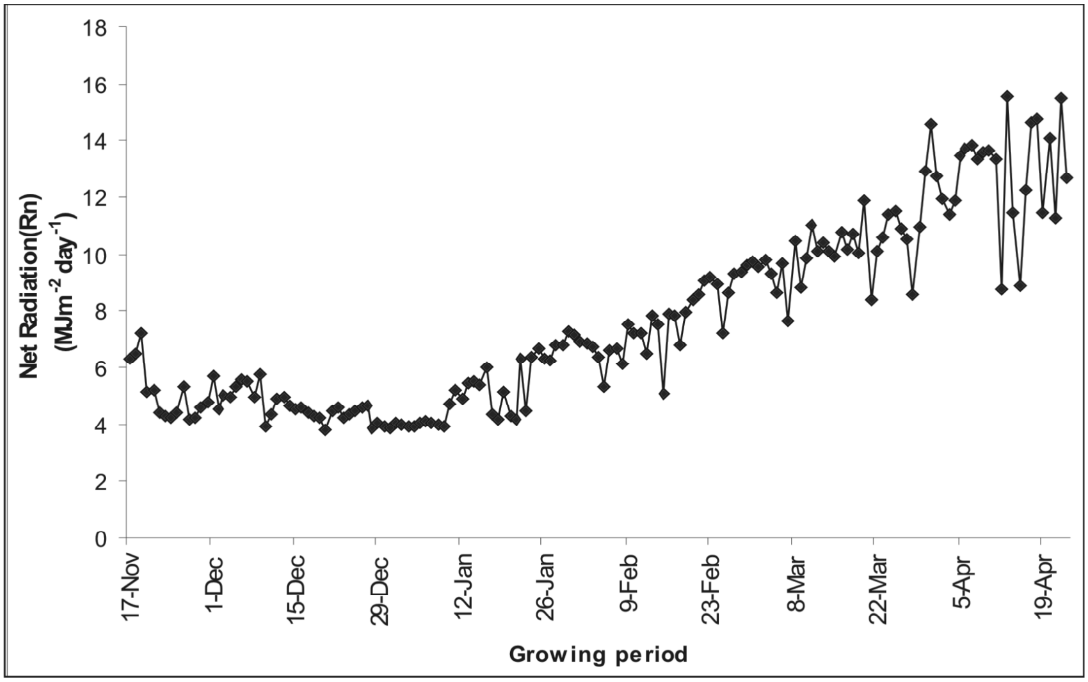

Figure 1: Daily Net Radiation (MJ/m²/day) estimated at experimental site.

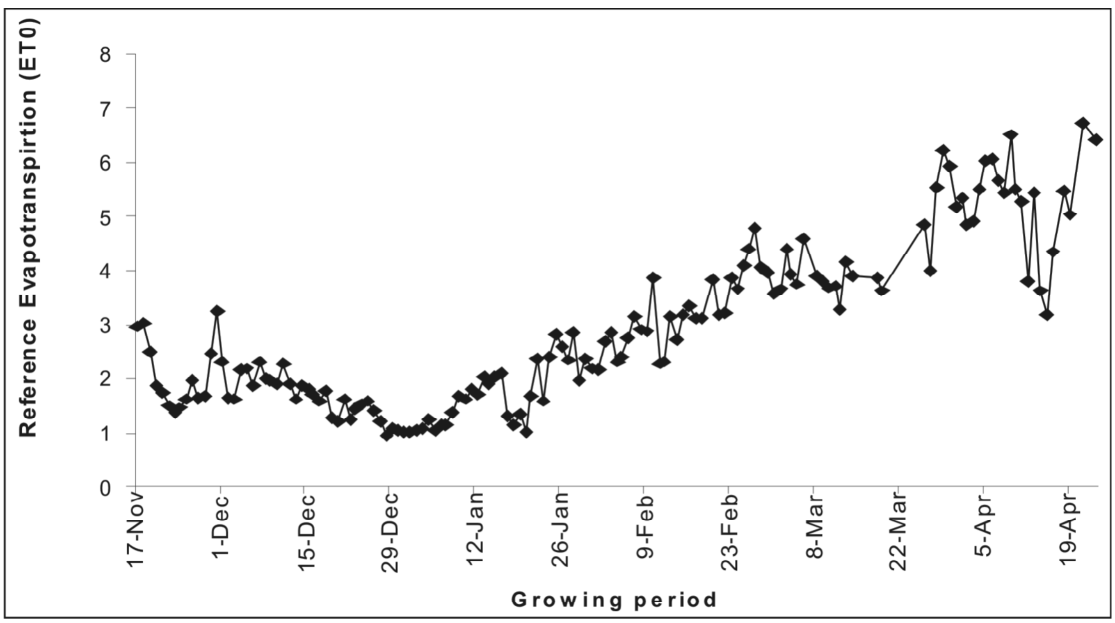

Figure 2: Daily Reference Evapotranspiration (mm/day) estimated at experimental site.

Because no reference evapotrans-piration was measured at the experimental site, the estimated reference crop evapotranspiration was validated by pan evaporation by multiplying the pan evaporation data with correction factor. The Figure 3 showed the relationship between estimated reference evapotranspiration by Penman Monteith equation and calculated by pan evaporation had good correlation (R^2 = 0.87).

Crop Stages

The number of days taken to reach different stages during the crop growth period were noted carefully from day-to-day observations. According to FAO-56 the different stage initial, development, mid-season, and late season stages were calculated based on the crop coverage data as suggested by FAO-56.

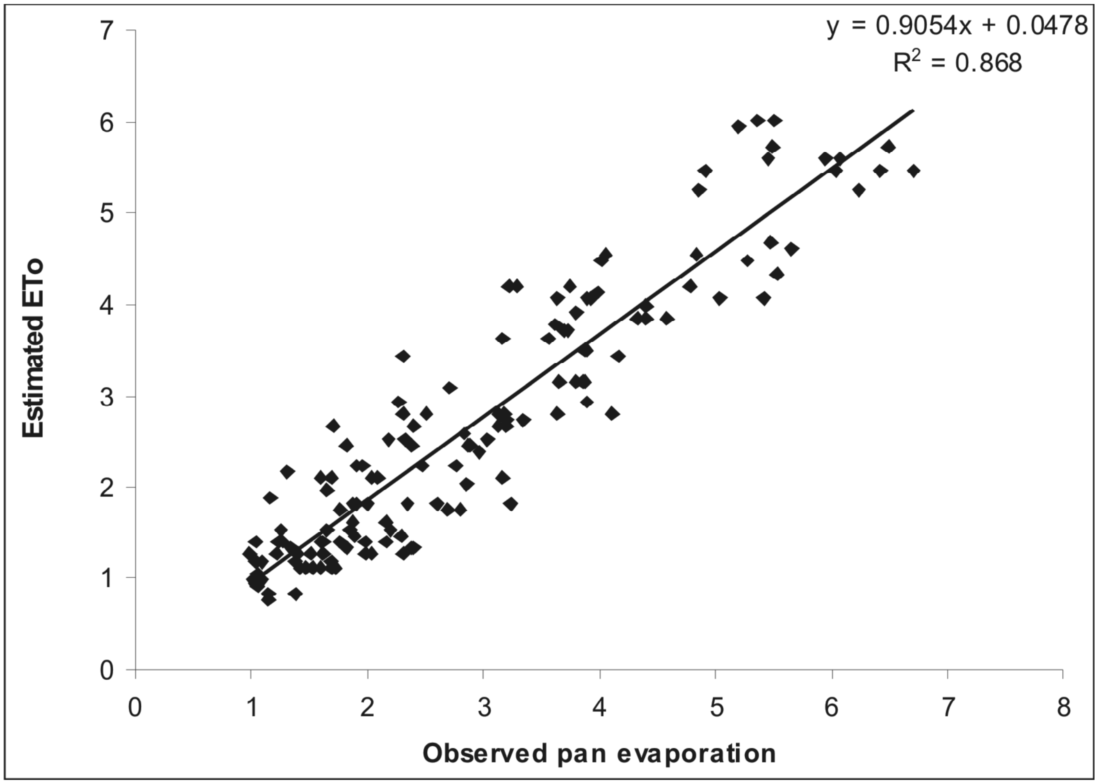

Figure 3: Relation between reference evapotranspiration estimated through Penman-Monteith equation and Pan Evaporation.

The initial stage was up to 45 days after sowing in first sowing and up to 50 days after sowing in the second and third sowing. The development stage was between 45 to 65 days in first sown crop and 50 to 60 days after sowing in second and third sown crop. The mid stage was between 65 to 135 days in first sown crop, 60-135 in second sown crop and 60 to 122 in third sown crops. The late stage was between 135 to145, 135 to 144 and 122 to 130 days after sowing in different weather conditions. Both varieties had the different stages almost at similar interval.

Estimation of Single (K_c) and Basal crop coefficient (K_{cb})

The calculated crop coefficients for initial stage, the mid stage and late stage for two varieties of wheat under variable weather conditions are sown in the Figure 4. Plant parameters influencing the crop coefficient calculation are soil cover and plant height and a climatic correction for relative humidity and wind speed. The values of Kc for both varieties were almost similar because of similar condition for crop grown and similar types of plant characteristics. The K_c value was found to be 0.7 during initial stage under different weather conditions for both varieties. During development stage the value was 0.908 and 0.945, 0.908 and 0.912, 0.893 and 0.936 for varieties HD-2894 and HD-2851 respectively under different weather conditions. During mid stage the value was 1.160 and 1.159, 1.168 and 1.169, 1.171 and 1.170 for varieties HD-2894 and HD-2851 respectively under different weather conditions. During late stage the value was 0.262, 0.259 and 0.260, 0.267 and 0.266 for HD-2894 and HD-2851 under different weather conditions. There was no significant different for value of single crop coefficient in different stage for both the varieties.

The K_{cb} curve is divisible into four growing stage periods, *i.e.* the initial stage, the development stage, the mid-season stage, and the late season stage (Figure 5). The K_{cb} values suggested by FAO-56 for the initial, mid-season, and late season stages were calculated for the climatic conditions of the study area. After adjustment, the K_{cb} of wheat in the initial stage was 0.141 and 0.147, 0.118and 0.117, 0.125 for varieties HD-2894 and HD-2851 respectively under different weather conditions. During development stage the value was 0.765 and 0.771, 0.704 and 0.703, 0.820 and 0.821 for varieties HD-2894 and HD-2851

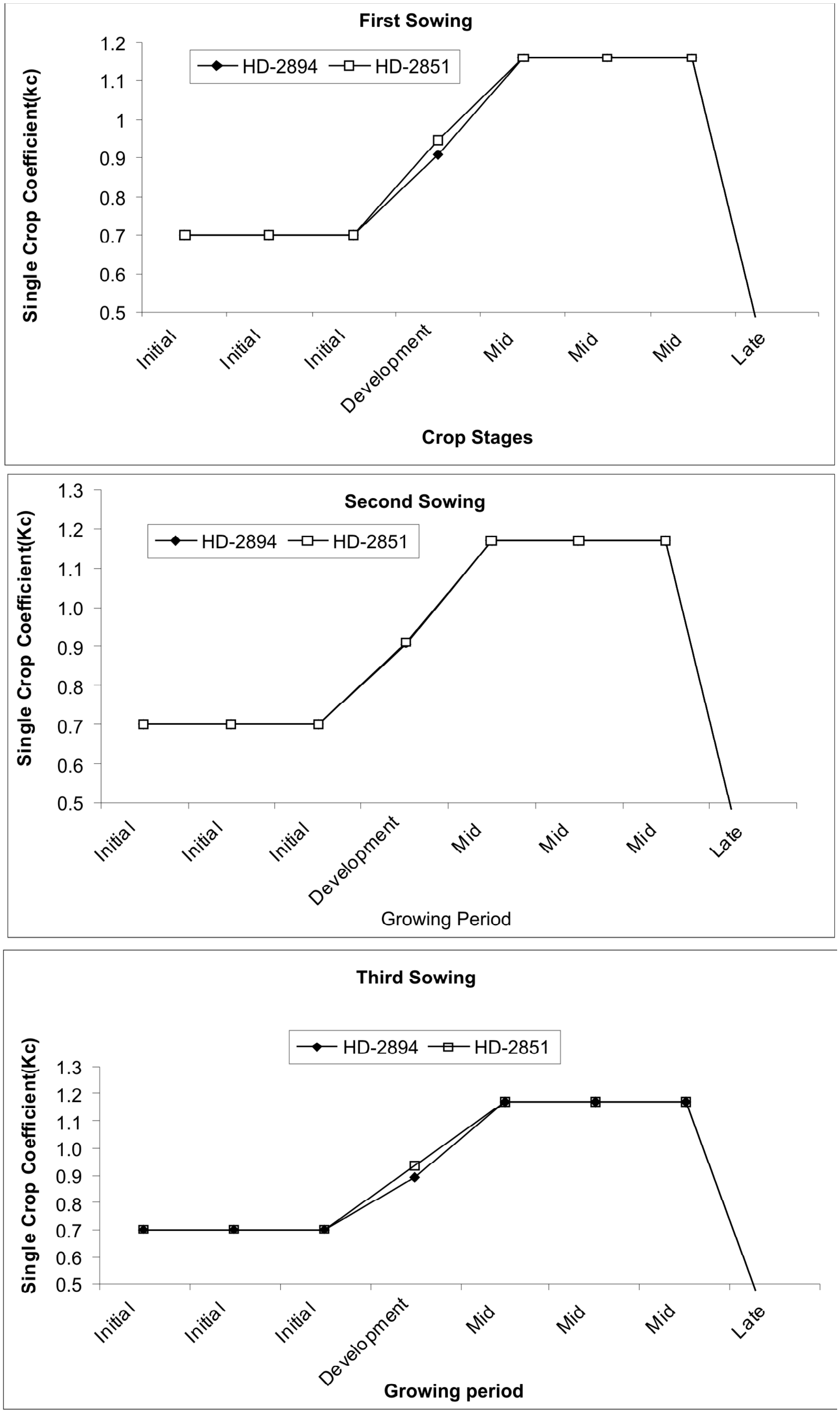

Figure 4: Adjusted Single Crop Coefficient at Experimental Site.

respectively under different weather conditions. During mid stage the value was 1.068 and 1.071, 1.12, 1.105 for varieties HD-2894 and HD-2851 respectively under different weather conditions. During late stage the value was 0.163, 0.164 and 0.159, 0.160 and 0.167 and 0.166 for varieties HD-2894 and HD-2851 respectively under different weather conditions. Both verities have similar value of basal crop coefficient in different stages.

Although the *Kc* and *Kcb* exhibited similar kind of response to different weather conditions but K_{cb} was able to produce some higher difference during mid stage with respect to weather conditions and varieties. During this active growth period the percentage of bare ground was very less owing to the faster development of canopy which made the transpiration component much higher than that of evaporation. As the K_{cb} is more related to transpiration than K_c which integrates both the transpiration and evaporation components. Thus K_{cb} is the better indicator of crop water use. Bandyopadhyay and Mallick (2003) observed that no significant difference existed between estimated and FAO reported K_c values of predetermined four stages for wheat but our results suggest that the average K_c and K_{cb} values differed. This may be attributed to the fact that earlier study was made under the humid tropical climatic conditions whereas our study was conducted under the semi-arid subtropical climatic regions of Delhi. This ushered the need of development of regional and growth stage-specific crop coefficient values of different crops for precise application of irrigation water which otherwise lead to over or under irrigation having negative impacts.

Daily Calculation of Soil Evaporation Coefficient (K_e)

Soil evaporation coefficient K_e, is a function of growth period is affected by the soil water characteristics, exposed and wetted soil fraction, and soil water balance. The variation of K_e in the crop growing season are shown in the figure 6. In the initial stage, the effective fraction of soil surface covered by crop was small, and thus, soil evaporation losses were high during the period. Following irrigation, K_e reached its maximum values (1.04 to 1.07). K_e had a sharp fall when the soil evaporation switched from stage 1 to stage 2. In the development stage, the effective fraction of soil surface covered by mustard crop increased, and the K_e value decreased step by step. In the mid-season stage, the effective fraction of soil surface covered by mustard reached maximum and the soil water losses mainly depended on the crop transpiration. The small exposed soil fraction resulted in a small K_e value. The value of K_e increased after irrigation and precipitation and decreased simultaneously.

Crop evapotranspiration (ET_c) using single and dual crop coefficient

The crop evapotranspiration (ET_c) calculated using single crop coefficient for different varieties under different weather condition are sown in the Figure 7. During the initial stage of crop growth, which is the period from sowing through 45-50 days, the ET_c values are very low except during irrigation events. The ET_c values increase during the crop development stage and reach its peak during the mid-season stage. The ET_c values decline rapidly during the last crop growth stage. The average values of ET_c for different stages are shown in the Table 1.

Total value of the crop evapotranspiration (ET_c) estimated by single crop coefficient approach was 386.2, 402.5 and 318.2 mm for HD-2894 and 387.1, 402.6 and 318.8 for HD-2851under different weather conditions.

Table 1
Average value of crop evapotranspiration estimated using single crop coefficient approach in wheat at different stage

Varieties	*Initial Stage*	*Development Stage*	*Mid Stage*	*Late Stage*
First Sowing (15th November)				
HD-2894	1.240	1.348	4.108	1.470
HD-2851	1.240	1.412	4.103	1.466
Second Sowing (30th November)				
HD-2894	1.196	1.608	4.164	1.461
HD-2851	1.196	1.608	4.165	1.462
Third Sowing (15th December)				
HD-2894	1.196	1.578	3.701	1.493
HD-2851	1.196	1.655	3.699	1.488

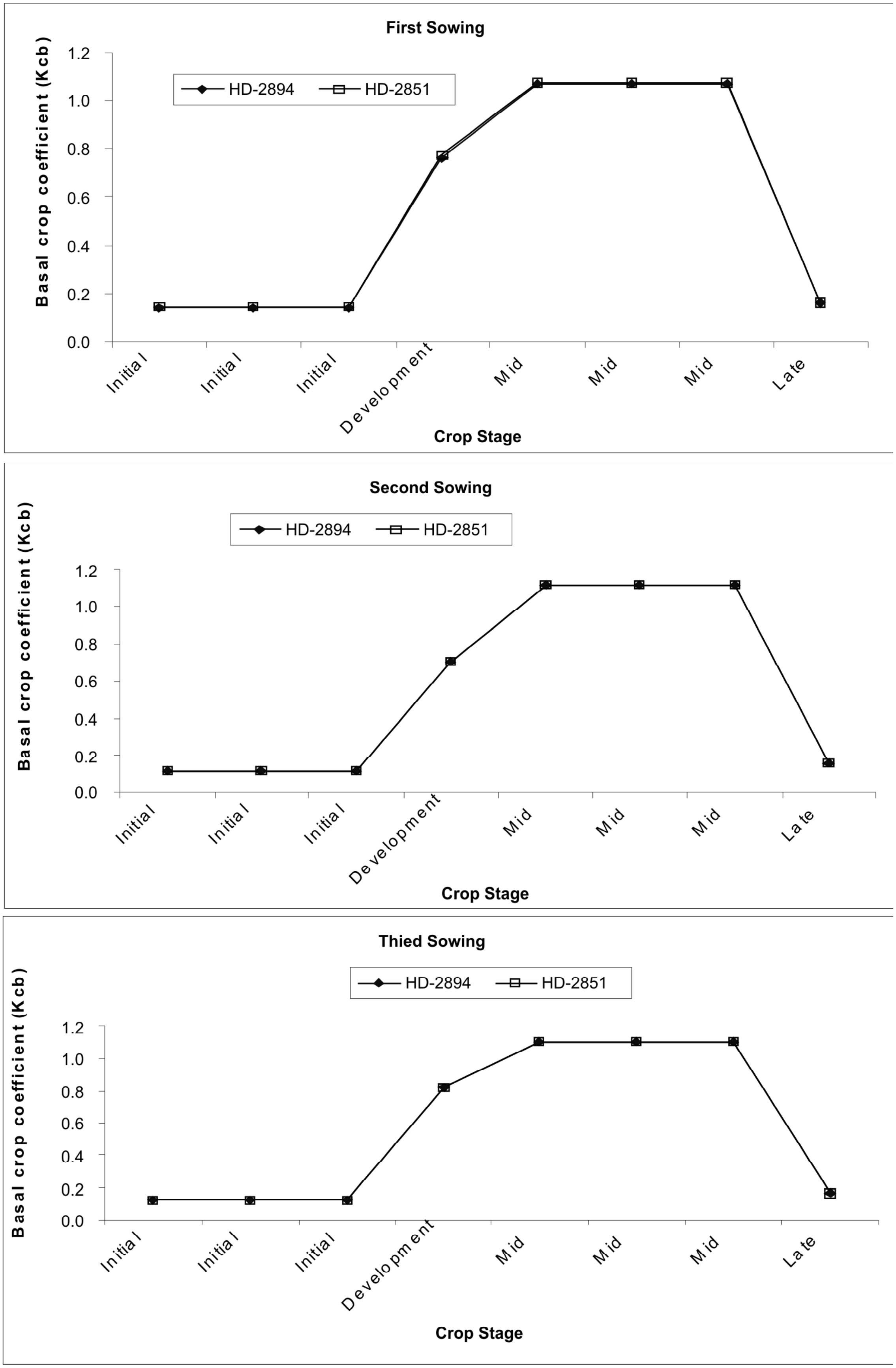

Figure 5: Adjusted Basal Crop Coefficient at Experimental Site.

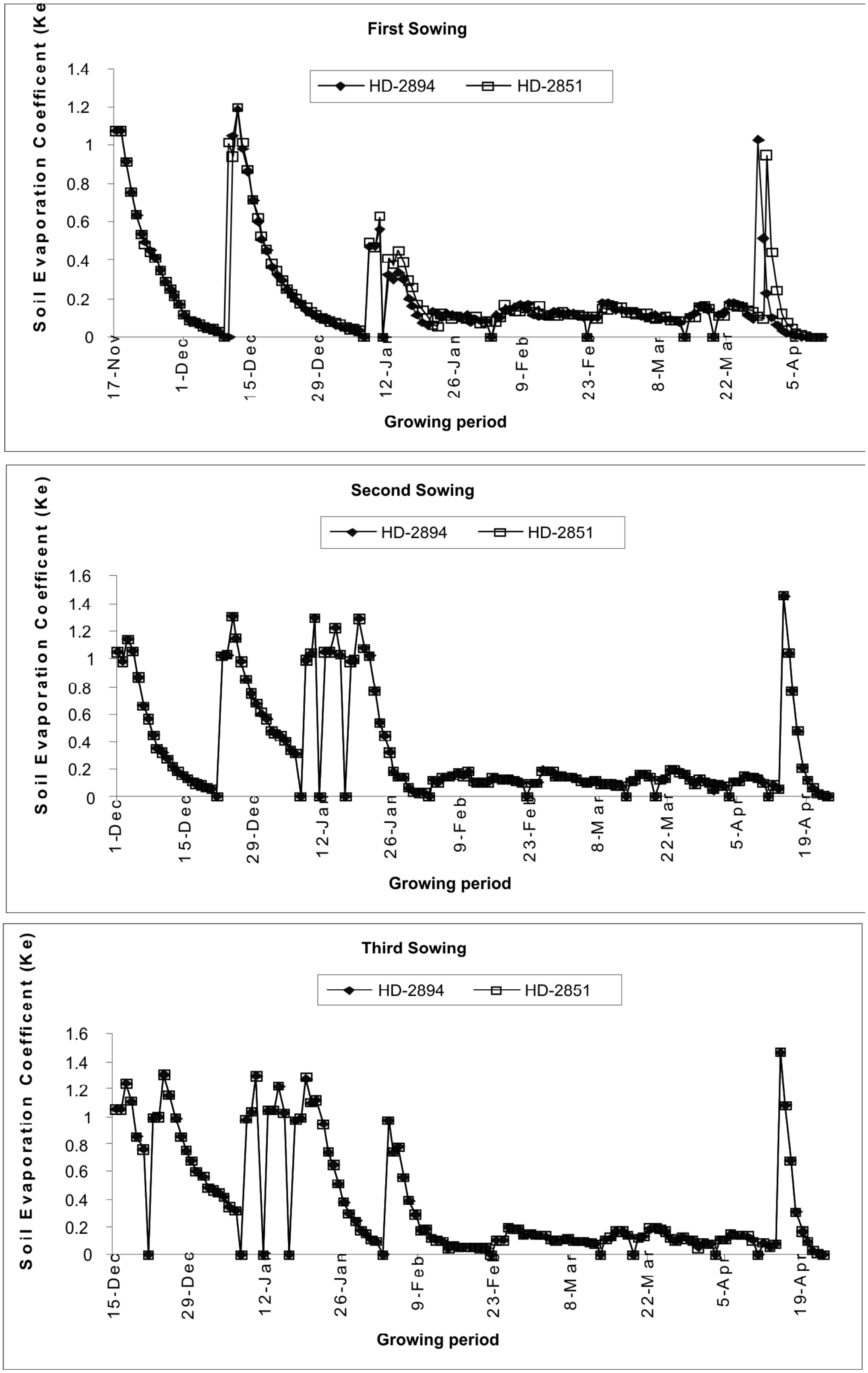

Figure 6: Variation in Soil Evaporation Coefficient (K_e) with crop growing period.

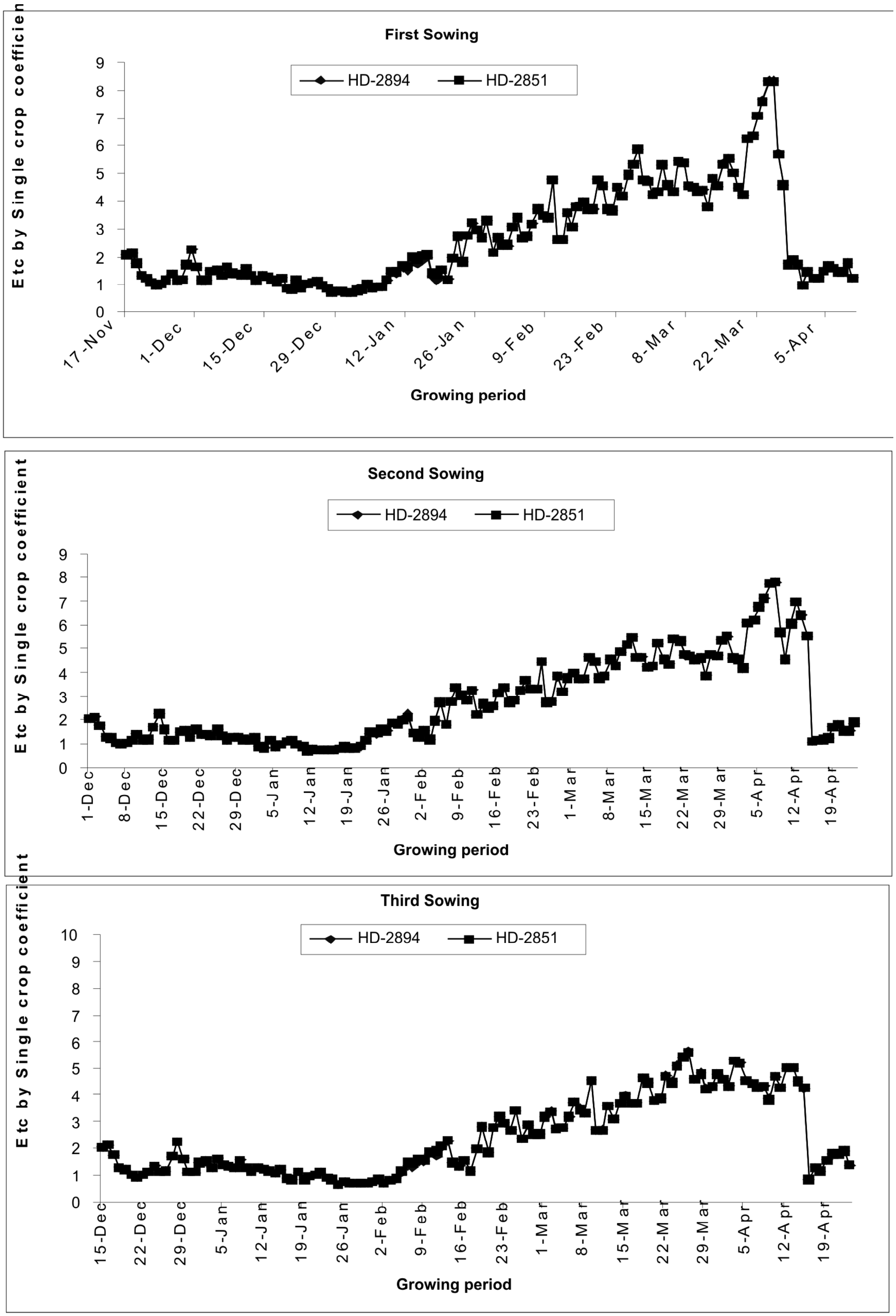

Figure 7: Calculated Crop Evapotranspiration through Single Crop Coefficient under variable weather conditions.

The crop evapotranspiration (ET_c) calculated using dual crop coefficient for different varieties under different weather condition are sown in the Figure 8. Similar to single crop coefficient approach during the initial stage of crop growth, which is the period from sowing through 40-45 days, the ET_c values are very low except during irrigation events. The ET_c values increase during the crop development stage and reach its peak during the mid-season stage. The ET_c values decline rapidly during the last crop growth stages. Total value of the crop evapotranspiration (ET_c) was 396.6, 460.4 and 432.0 mm for HD-2894 and 400.5, 460.4 and 431.9 for HD-2851under different weather conditions. The average values of ET_c for different stages are shown in Table 2.

Crop water requirement vary during the growing period, mainly due to variation in crop canopy and climatic conditions, and related to soil-crop management and irrigation methods Nearly 99% of water uptake by plants accounts for evapotranspiration (ET) and hence that the management of actual crop evapotranspiration (ET_c) on a daily scale over the whole vegetative cycle can be assumed as equivalent to the water requirement of the given crop. Knowledge of precise crop water requirement is crucial for water resources management and planning in order to improve water–use-efficiency at regional, national and global scale (Chuanyan *et al* 2005; Chuayun and Zhongren N., 2007). Therefore, it is necessary to improve the water use efficiency in agriculture to sustain the natural input resource (water) and the crop production in order to meet the demand of food for billions of people in coming future. This can only be achieved by employing proper technologies for saving of irrigation water at each application time.

Table 2
Average value of crop evapotranspiration estimated using single crop coefficient approach in wheat at different stage

Varieties	*Initial Stage*	*Development Stage*	*Mid Stage*	*Late Stage*
First Sowing (15th November)				
HD-2894	0.965	1.483	4.468	0.978
HD-2851	1.017	1.554	4.439	1.187
Second Sowing (30th November)				
HD-2894	1.187	2.445	5.189	2.299
HD-2851	1.187	2.444	5.189	2.299
Third Sowing (15th December)				
HD-2894	1.349	3.286	5.560	2.585
HD-2851	1.348	3.287	5.560	2.584

Present studies showed that the FAO Penman Monteith method was used to estimate the ET_0 value in the study area had good correlation with evaporation calculated by pan evaporation (the correlation coefficient, $R^2 = 0.87$). The total value of ET_0 was depending upon weather conditions at the experiment site during crop growing period. The ET_c value was found to be less during initial stage, increased during development stage and reached maximum during mid stage season. The total *ETc* value was ranged between 397 mm to 467mm as calculated by dual crop coefficient and 318 mm to 403 mm as calculated by single crop coefficient under different weather conditions at the experiment site during crop growing period. Since *ETc* calculated by dual crop coefficient consider the effect of soil evaporation coefficient and basal crop coefficient both therefore the values calculated by dual crop coefficient are more reliable as compared to single crop coefficient. Therefore ET_c value calculated from the dual crop coefficient can be used for the irrigation scheduling in the crop for optimum use of irrigation water

Water Use Efficiency (WUE)

The values of water use efficiency (WUE) calculated based on the single crop coefficient were found to be 10.3, 9.5, 11.7 Kg/ha/mm for HD 2894 and 11.8, 10.9 and 12.6 kg/ha/mm for HD 2851 under different weather conditions. The value of Water use efficiency (WUE) calculated based on the dual crop coefficient were found to be 10.1, 8.8, 8.8 kg/ha/mm for HD 2894 and 11.6, 10.2 and 9.5 kg/ha/mm for HD 2851 under different weather conditions. The value of Water use efficiency (WUE) calculated based on the soil water balance equation were found to be 10.3, 9.2 and 9.2 kg/ha/mm for HD 2894 and 11.8, 10.6 and 10.0 kg/ ha/mm for HD 2851 under different weather conditions (Table 3).

The water use efficiency calculated by all three approaches was found to be more in HD 2851 as compared to HD2894. HD 2851 had 7 to 14% more

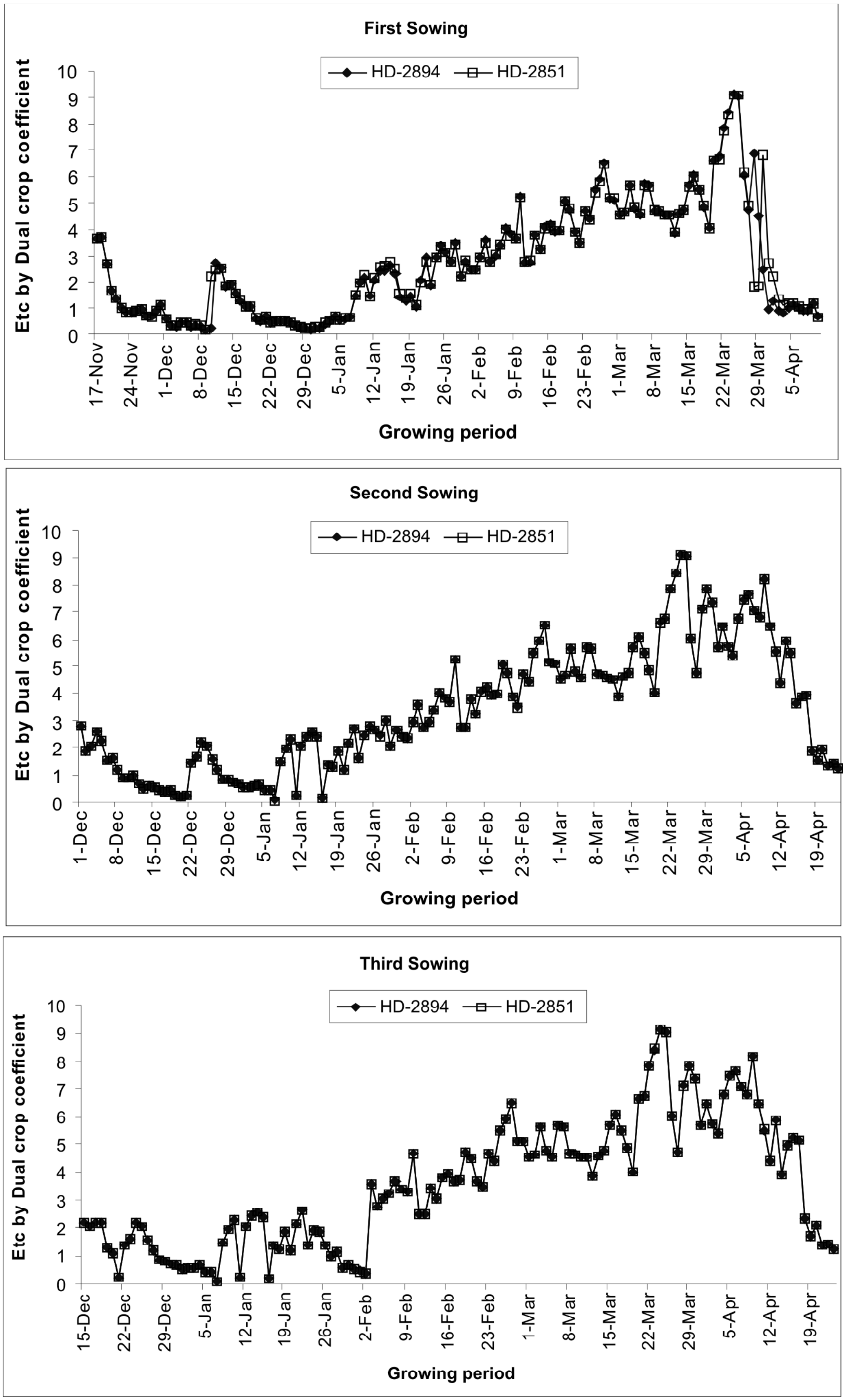

Figure 8: Calculated Crop Evapotranspiration through Dual Crop Coefficient under variable weather conditions.

Table 3
Water use efficiency calculated from different methods under different weather conditions (Mean ± Standard Error)

Water use efficiency	*First sowing*	*Second sowing*	*Third sowing*	*First sowing*	*Second sowing*	*Third sowing*
Varieties	HD2894	HD2851				
Seed Yield	4036±251.1	3975±138.9	3845±191.8	4621±161.6	4585±211.4	4134±179.5
Single Crop Coefficient	10.3±1.24	9.5± 1.21	11.7±1.45	11.8±2.01	10.9±1.41	12.6±1.36
Dual crop coefficient	10.1±1.58	8.8± 1.36	8.8±1.64	11.6±1.98	10.2±2.12	9.5±1.29
Soil water balance equation	10.3±1.62	9.2±1.29	9.2±1.28	11.8±1.36	10.6±1.95	10.0±2.09

value of water use efficiency as compared to HD 2894 respectively in different weather conditions, when calculated by single crop coefficient approach, 7 to 15% more value when calculated by dual crop coefficient approach and 9 to 15 % when calculated by water balance equation.

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