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## Assessment on water requirement and irrigation scheduling in Field Pea under elevated thermal regimes: A Simulation Study

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### Abstract

The present experiment was laid out on Field Pea (cv. AP 3) at the research farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal during *rabi* seasons of 2017-18 and 2018-19 to estimate the  $ET_0$  and water requirement from Pea field using CROPWAT 8.0 model which will eventually help farmers in irrigating the crop in future also. Seasonal mean reference crop evapotranspiration was relatively higher ( $2.12 \text{ mm day}^{-1}$ ) during first season than the second one ( $2.04 \text{ mm day}^{-1}$ ). Radiation use efficiency has been found to be directly proportional to the  $ET_0$  rate. Model derived total irrigation requirement and actual crop evapotranspiration remained maximum as 159.3 mm and 161 mm respectively during *rabi* 2017-18. Increment of temperature by 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 °C from the current scenario, resulted in increasing the seasonal  $ET_0$  by 1.44, 2.40, 3.84, 5.76, 6.73 and 8.17%, respectively and water requirement by 2.41, 5.40, 7.56, 10.16, 13.02 and 14.54% in alike order. Two specific crucial crop growth stages *viz.* initial (7-10 DAS) and mid development (35-40 DAS) were simulated based on critical depletion for scheduling irrigation under already over exploited water resource zones. Therefore, the study concluded that need based judicious irrigation supplementation at critical stages could be a realizable option for effective planning and management of moisture regimes at optimum level in view of persisting climate change conditions.

**Keywords:** CROPWAT 8.0, Reference crop evapotranspiration, Irrigation requirement, Radiation use efficiency, Critical depletion, Climate change

### Introduction

Pea (*Pisum sativum* L.) is a popular vegetable and pulse crop of India and due to its multifarious use in preparation of different vegetarian dishes, it is consumed throughout the world. Peas are high in digestible protein, carbohydrates, fats, minerals and vitamins (Tao *et al.*, 2017) [16]. Farmers in India now-a-days prefer field pea over chickpea and different beans because of the fact of being able to be sown late but harvested earlier compared to major cereal crops while maintaining economic yield still stable. In India, as per 12<sup>th</sup> fifth year plan, field pea was cultivated in 9.01 lakh ha area with a gross production of 8.49 lakh tonnes and a productivity of 942 kg/ha. West Bengal also contributed significantly in this statistics. With a land coverage of 0.14 lakh ha and production of 0.16 lakh ha, field pea yielded almost around 1183 kg/ha in West Bengal as recorded during 12<sup>th</sup> Five-year plan period (Anonymous, 2017) [3].

Climate change has popped up as a critical threat to agriculture influencing crop phenology, water requirement, pest dynamics, nutritional qualities of food and thus, grain yield, crop biomass and ultimately food security in near future. The predicted climate change in India based on different Representative Concentration Pathways indicated that there is an increase in evapotranspiration ( $ET_0$ ) due to increasing minimum and maximum air temperatures. Hence, with increase in  $ET_0$ , apart from cereals, legumes will also not be able to acquire sufficient moisture to meet up their regular physiological processes. Schewe *et al.* (2014) [15] reported that the adverse effect of climate change on already stressed water resources. Besides this, crop demand growth due to socioeconomic development will lead to increases in irrigation water requirements in most regions (Nechifor and Winning, 2017) [13]. Due to unavailability of adequate facilities sometimes direct experimentation may not be a possible option remain for

researchers and policy makers. Use of simple robust simulation model in this aspect can ideally determine the  $ET_0$  and water requirement of crops. The advantages of using models are that simulations are cheaper and faster than field trials and that you can get more and higher level of detail from the simulation runs (El-Shafie *et al.*, 2018<sup>[8]</sup>; Dewedar *et al.*, 2019)<sup>[6]</sup>.

One such irrigation model namely CROPWAT has been used by the irrigation engineers and scientists to determine the water requirement of different crops both in present and future conditions. CROPWAT is a windows-based decision support system developed by the Land and Water Development Division of FAO for estimation of  $ET_0$  for planning and management of irrigation. Different scientists are of the opinion that it is possible to increase water productivity of field crops through proper irrigation scheduling either by applying water that matches the crop evapotranspiration or by providing irrigation at critical growth stages (Kipkorir *et al.*, 2002; Kar *et al.*, 2005)<sup>[12, 10]</sup>. Earlier, several studies regarding the water requirement estimation of different legumes crops has been done. But, sufficient literature on ET estimation from Pea field particularly in West Bengal state is still not available with us. Along with that, proper usage and management of water resource systems require knowledge of the actual evapotranspiration (AET) and irrigation water requirement (IWR) of the crops (Allen *et al.*, 2005; Droogers *et al.*, 2010)<sup>[7, 1]</sup>. Therefore, keeping these facts in consideration, present experiment was formulated to estimate the water requirement of field pea using CROPWAT (v. 8.0) in new alluvial agro-climatic zone of West Bengal which will eventually enable the farmers in irrigation scheduling of Pea crop in future under warming climatic conditions also.

## Materials and methods

### Site description

The present experiment was conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, representing the new alluvial agro-climatic zone of West Bengal. The study area is closer to Tropic of Cancer region (22°57' N Latitude, 88°20' E Longitude with an altitude of 9.75 m above mean sea level). The experimental site is characterized by sub-tropical humid climatic zone with an average annual rainfall of 1470 mm varying between 1200 mm to 1700 mm. During months of June to September, relative humidity remained quite higher between 55-90% and more than 80% rainfall is received from south west monsoon. Recommended crop management practices were followed

throughout the growing period of Field Pea. The soil was of sandy loam in texture and mainly alluvial in nature (Entisol) with well levelled and drained.

### Software used and input set

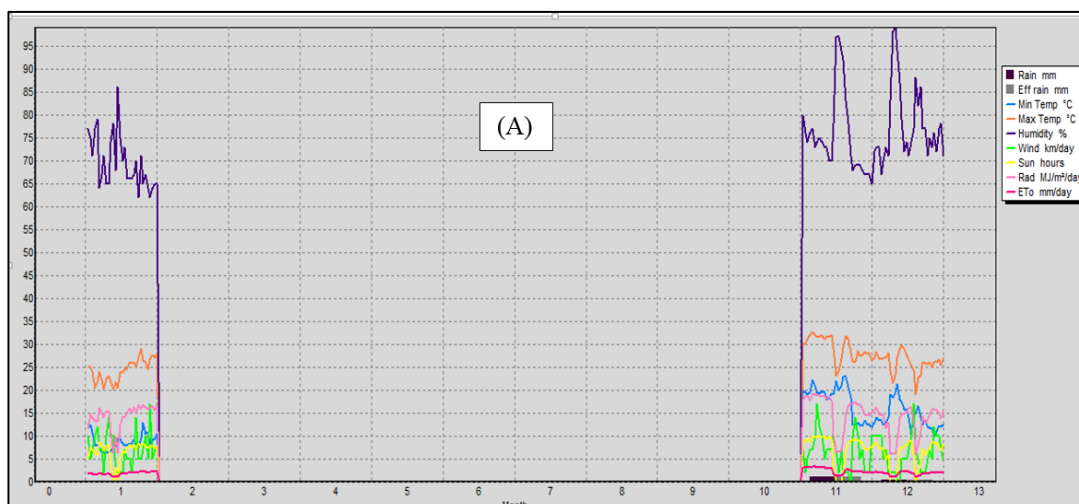
The  $ET_0$  and water requirement of Field Pea was estimated by CROPWAT 8.0 software during rabi seasons of 2017-18 and 2018-19 for Kalyani region of West Bengal. CROPWAT is a decision support system which computes the crop water requirements from crop consumptive water use (Crop evapotranspiration) which is again the product between model simulated reference ET and the crop coefficient value. At the same time the model needs to be fed with different soil, weather and crop data from experimental field as input (Table 1 & 2) for calculating  $ET_0$  value with optimum accuracy. Different weather parameters namely maximum and minimum temperature, wind speed, sunshine hours, relative humidity and rainfall during both crop growing period were collected from AICRP on Agrometeorology, Directorate of Research, B.C.K.V., Kalyani, and demonstrated in Fig 1 & 2. Apart from this, other Input data required for running the model *viz.* Kc values, rooting depth, critical depletion (fraction) and yield response factor were collected by model processing and field observations (Table 1).

**FAO Penman-Monteith method:** It is a combination approach which combined the aerodynamic and heat balance equations into one equation. This equation was used by CROPWAT (Allen *et al.* 1998<sup>[2]</sup>) for estimating reference crop evapotranspiration ( $ET_0$ ) given below:

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \left( \frac{900}{T + 273} \right) u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)}$$

### Where

- $ET_0$  = Reference evapotranspiration ( $\text{mm day}^{-1}$ )
- $R_n$  = Net radiation at crop surface ( $\text{MJ m}^{-2} \text{day}^{-1}$ )
- $G$  = Soil heat flux density ( $\text{MJ m}^{-2} \text{day}^{-1}$ )
- $T$  = Mean daily air temperature at 2 m height ( $^{\circ}\text{C}$ )
- $u_2$  = Wind speed at 2 m height ( $\text{m s}^{-1}$ )
- $e_s$  = Saturation Vapour Pressure (kPa)
- $e_a$  = Actual vapour pressure (kPa)
- $e_s - e_a$  = Saturation vapour pressure deficit (kPa)
- $\Delta$  = Slope of vapour pressure curve ( $\text{kPa } ^{\circ}\text{C}^{-1}$ )
- $\gamma$  = Psychrometric constant



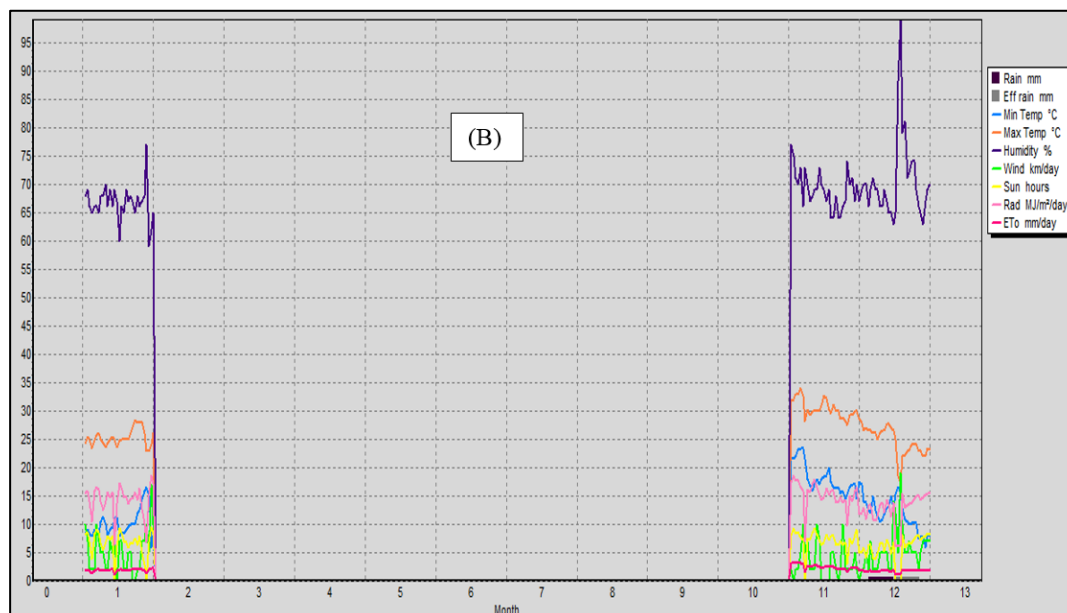


Fig 1: Variation in meteorological parameters during field Pea growing rabi seasons of 2017-18 (A) and 2018-19 (B).

Table 1: Input data (Own processed) provided in crop file of CROPWAT during rabi seasons of 2017-18 and 2018-19

Crop Name- Field Pea	Planting date: 01/11 Harvesting date: 31/01				
Stage	Initial	Development	Mid-season	Late season	Total
Stage days	16	25	30	21	90
Kc values	0.50	---	1.15	1.10	
Rooting depth (m)	0.15	---	0.45	0.60	
Critical depletion (fraction)	0.60	---	0.60	0.90	
Yield response (fraction)	0.20	0.60	0.50	0.40	1.70
Crop height (m)			0.80		

Table 2: Input data feed into soil file of CROPWAT 8.0 to drive the model

Soil name-	Sandy loam
Total Available Soil Moisture (FC-WP)	225 mm/meter
Maximum Rain infiltration Rate	288 mm/day
Maximum rooting depth	60 centimeters
Initial soil moisture depletion (as% TAM)	40%
Initial available soil moisture	135 mm/meter

## Results and Discussion

### Radiation Use and Reference crop evapotranspiration (ET<sub>o</sub>)

Both Table 3 & 4. revealed the radiation use efficiency and reference ET (ET<sub>o</sub>) from Pea field computed through CROPWAT 8.0 during rabi seasons of 2017-18 and 2018-19 respectively. During 2017-18, minimum and maximum temperature ranged between 8.8-17.8 °C and 24.4-29.3 °C. Mean relative humidity remained between 70-78 per cent along with a moderate wind speed of 7 km/day (Table 3). Sunshine hours stayed quite lower ranging from 6.1-7.6 hours during the entire crop growing period. Maximum radiation use efficiency estimated by the software was 15.7 MJ m<sup>-2</sup> day<sup>-1</sup> during November month while the minimum data (13 MJ m<sup>-2</sup> day<sup>-1</sup>) being recorded during December month. The model predicted significantly higher reference ET<sub>o</sub> of 2.55 mm/day during November month and the lowest value (1.9 mm/day)

of it was recorded during December month. Significant reduction in temperature, sunshine hours and wind speed along with enhancement of relative humidity during December month resulted in lower reference ET<sub>o</sub> as well as radiation use by field pea at first experimental year. On the other hand, during second year of experiment, minimum and maximum temperature was recorded between 10.2-18.2 °C and 25.3-30.4 °C. This range was however, quite larger than that of first year of experiment. Humidity range was 67-71 per cent and it was lower than the previous year. Both wind speed (3-5 km/day) and sunshine hours (5.8-7.1 hours) stayed lower than the last year of experiment. Maximum radiation use efficiency estimated by the software was 15.2 MJ m<sup>-2</sup> day<sup>-1</sup> during November month while the minimum data (12.7 MJ m<sup>-2</sup> day<sup>-1</sup>) being recorded during December month. The model simulated significantly higher reference ET<sub>o</sub> of 2.46 mm day<sup>-1</sup> during November month and the lowest value (1.73 mm day<sup>-1</sup>) of it was recorded during December month. Decrement in different weather variables during rabi season of 2018-19 than that of previous rabi season experiment simultaneously contributed in lowering both reference ET<sub>o</sub> and radiation use by field crop during second crop season. Gangwar *et al.* (2017) [9] computed the average daily reference evapotranspiration in Bina command of Madhya Pradesh by the Penman Monteith method (CROPWAT 8.0) as 4.62 mm/day.

**Table 3:** Meteorological conditions and Reference ET (ET<sub>o</sub>) during Field Pea growing season (*Rabi* 2017-18)

Rabi season of 2017-18							
Month	Min Temp. (°C)	Max Temp. (°C)	Humidity (%)	Wind Speed (km day <sup>-1</sup> )	Sunshine hours	Radiation Use Efficiency (MJ m <sup>-2</sup> day <sup>-1</sup> )	ET <sub>o</sub> (mm day <sup>-1</sup> )
November	17.8	29.3	75	7	7.6	15.7	2.55
December	14.3	25.9	78	6	6.1	13	1.9
January	8.8	24.4	70	7	6.6	14.3	1.91
Average	13.63	26.53	74.33	6.67	6.77	14.33	2.12

**Table 4:** Meteorological conditions and Reference ET (ET<sub>o</sub>) during Field Pea growing season (*Rabi* 2018-19)

Rabi season of 2018-19							
Month	Min Temp. (°C)	Max Temp. (°C)	Humidity (%)	Wind Speed (km day <sup>-1</sup> )	Sunshine hours	Radiation Use Efficiency (MJ m <sup>-2</sup> day <sup>-1</sup> )	ET <sub>o</sub> (mm day <sup>-1</sup> )
November	18.2	30.4	69	3	7.1	15.2	2.46
December	11.7	24.5	71	6	5.8	12.7	1.73
January	10.2	25.3	67	5	6.7	14.3	1.93
Average	13.37	26.73	69	4.67	6.53	14.07	2.04

### Water requirement and actual ET estimation

The irrigation water requirement and crop evapotranspiration from Pea field during both rabi seasons of 2017-18 and 2018-19 was estimated by using CROPWAT 8.0 software which was depicted in Table 5. At first season, it was observed that maximum crop evapotranspiration (23.8 mm) was recorded during 3<sup>rd</sup> dekad of December followed by 2<sup>nd</sup> dekad of December (21.2 mm). Minimum ET<sub>c</sub> (11.7 mm) was recorded at 2<sup>nd</sup> dekad of November. This may be due to development of more canopy structure during December contributing much towards evapo-transpiration. Irrigation requirement by field pea was maximum (23.7 mm) at 3<sup>rd</sup> dekad of December and minimum (11.3 mm) at 2<sup>nd</sup> dekad of November during first crop year. This may be due to utilization of remnant water by field pea during crop vegetative stage from the previous crop harvesting. During 2018-19, maximum evapotranspiration (21.7 mm) from field pea was obtained at 3<sup>rd</sup> dekad of December which was much lower than the previous year. Irrigation requirement results revealed that highest IR (21.5 mm) was recorded at 3<sup>rd</sup> dekad of December (crop development stage) whereas, lowest value (12.9 mm) was obtained at 2<sup>nd</sup> dekad of November. Irrigation

requirement of the crop seemed to increase as the crop moved towards maturity due to enhancement of ET<sub>c</sub> owing to more dry biomass production. Total crop evapotranspiration from Pea field was 161 mm during *rabi* season of 2017-18, which was much higher as compared to second experimental rabi crop season (156.2 mm). During 2017-18, total irrigation water requirement of field Pea was computed by CROPWAT 8.0 model to the tune of 159.3 mm which was also relatively higher than rabi season of 2018-19 in which IWR value remained as 155.5 mm. This might be due to overall decrease in meteorological parameters such as temperature, humidity, wind speed and sunshine hours during rabi season of 2018-19. In similar way, Desta *et al.* (2015) [5] calculated the net irrigation requirement of Chickpea crop at different growth stages such as during seedling (37.2 mm), vegetative (114.4 mm), mid growth stage (205.2 mm) and late growth stages (79.8 mm). Drastic reduction in water consumption by the crop was observed by them at crop maturity stages. Karuku *et al.* (2014) [11] predicted the tomato crop water requirements as 456.5 mm for the short rainy season while actual evapotranspiration (ET<sub>a</sub>) was 232.1 mm for the short rains giving a yield response factor of 0.49.

**Table 5:** Estimation of Irrigation requirement and Crop ET from Field Pea during *rabi* seasons of 2017-18 and 2018-19 using CROPWAT 8.0

Month	Dekad (10 days)	Stage	Kc (Crop Coefficient)	Mean T (10 days cum.)		Mean RH (10 days cum.)		ET <sub>c</sub> (mm for 10 days)		Effective rain (mm for 10 days)		IR (mm for 10 days)	
				2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Nov.	1	Init.	0.5	256.7	260.9	749	708.5	16	14	0.5	0	15.5	14
Nov.	2	Init.	0.52	247.4	242	829.5	680	11.7	13	0.4	0	11.3	12.9
Nov.	3	Init.	0.73	203.5	225.2	677	677.5	16.2	15.5	0.3	0.1	15.9	15.4
Dec.	1	Deve	0.97	205.5	197	777.5	682	17.1	17.1	0.2	0.2	16.9	17
Dec.	2	Deve	1.1	210	188.8	794.5	739	21.2	18	0.2	0.2	21	17.7
Dec.	3	Deve	1.1	208	176.5	831.5	757.5	23.8	21.7	0.1	0.2	23.7	21.5
Jan.	1	Deve	1.1	156.6	170.1	708	668.5	19.8	20.5	0.1	0.1	19.8	20.5
Jan.	2	Deve	0.99	157.8	178.6	720.5	661.5	16.2	18.7	0	0	16.2	18.7
Jan.	3	Mid	0.77	200.1	209.1	719.6	728.3	19	17.8	0	0	19	17.8
Total								161	156.2	1.8	0.8	159.3	155.5

### Impact of temperature increment on crop water requirement

The impact of elevated temperature on water requirement of field pea was evaluated by simulation studies and shown in Table 6. Increase in temperature by 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 °C from the existing experienced temperature was found to increase the reference ET by 1.44, 2.40, 3.84, 5.76, 6.73 and 8.17%, respectively and water requirement by 2.41, 5.40, 7.56, 10.16, 13.02 and 14.54% in the same order at Kalyani,

West Bengal. The seasonal ET<sub>o</sub> value ranged from 2.08 mm day<sup>-1</sup> at current scenario to 2.25 mm day<sup>-1</sup> under elevated temperature conditions up to +3.0 °C from the present temperature scenario. The corresponding simulated departures in case of irrigation water requirement of field pea varied between 157.4 mm at existing temperature conditions to 180.3 mm under elevated temperatures up to +3 °C. Hence, it was found that with increase in temperature, crop reference ET increased by almost 0.17 mm day<sup>-1</sup> vis-à-vis increment in

water requirement of pea was at around 23 mm from the current conditions also simulated. Banerjee *et al.* (2016) <sup>[4]</sup> conducted a study on potato as reference crop and they reported that at a temperature increase of 2 °C over normal, the mean Simulate evapotranspiration (SET) of potato would increase by 0.06 mm per day and the average Irrigation water requirement (IWR) would be 6.0 mm per season more. If the mean temperature would be 3 °C more than normal, the SET would be 0.16 mm day<sup>-1</sup> higher and the IWR 16.6 mm. This simulation study using CROPWAT 8.0 model denoted that current global warming scenario resulted in increased crop water requirement of field Pea under new alluvial agro-climatic zone of West Bengal and thus, requiring a planned action for future water uses in agriculture in this region.

**Table 6:** Variation of CROPWAT 8.0 simulated evapotranspiration (ET<sub>o</sub>) and irrigation water requirement (IWR) under current temperature condition and elevated thermal regimes for Field Pea

Temperature (°C)	Seasonal ET <sub>o</sub> mm/day	Seasonal IWR (mm)
Existing	2.08#	157.4#
Existing + 0.5	2.11 (+1.44%)*	161.2 (+2.41%)
Existing + 1.0	2.13 (+2.40%)	165.9 (+5.40%)
Existing + 1.5	2.16 (+3.84%)	169.3 (+7.56%)
Existing + 2.0	2.20 (+5.76%)	173.4 (+10.16%)
Existing + 2.5	2.22 (+6.73%)	177.9 (+13.02%)
Existing + 3.0	2.25 (+8.17%)	180.3 (+14.54%)

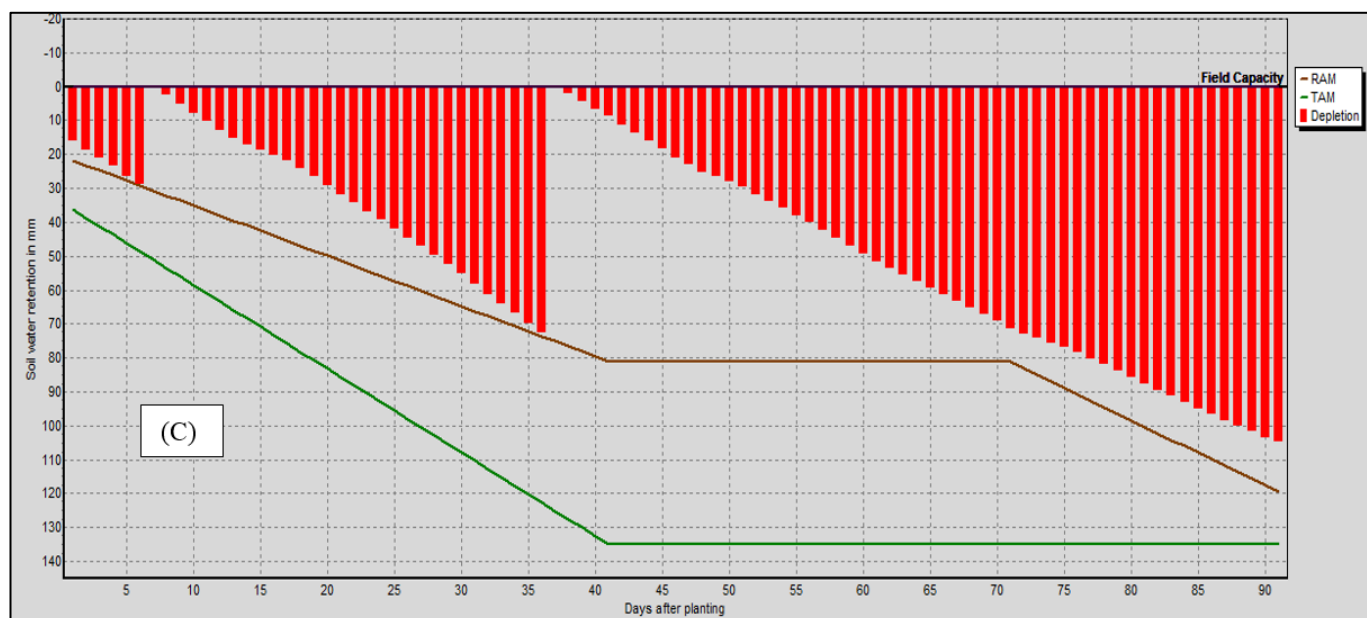
# denotes average of two season with their current temperature condition

\*values in parenthesis refers to percent departure from existing situations

### Irrigation scheduling

During both crop seasons, scheduling of irrigation on the basis of critical moisture depletion was decided by utilizing the graphical presentation from CROPWAT 8.0 which was revealed in Fig 2. During rabi season of 2017-18, at early crop emergence stage, rainfall was 0.2 mm and considering the

actual evapo-transpiration as 100 percent, moisture depletion percentage was calculated as 61 percent. Due to this irrigation should be applied at this stage considering it as critical water need stage for crop. The model calculated gross irrigation requirement and net irrigation requirement as 44.8 mm and 31 mm respectively considering the flow rate as 0.74 l/s/ha during that period. At similar conditions, during crop developmental phase, another irrigation was applied when rainfall received around 0.1 mm and then, gross irrigation requirement was measured as 107.7 mm with a flow rate of 0.42 l/s/ha. However, during second irrigation, the net irrigation requirement of the crop was computed as 76.6 mm by the model. At next year, there was no rainfall recorded during entire crop growth period. During 7<sup>th</sup> November, gross irrigation requirement was 43.9 mm with a flow rate of 0.73 l/s/ha and net irrigation was computed as 30.7 mm with a moisture depletion percentage of 60. However, at around 38 DAS, with same rate of depletion percentage, the model estimated gross irrigation requirement as 109.5 mm with a flow rate of 0.41 l/s/ha and net irrigation requirement was found as 76.6 mm during this period. Rahma *et al.* (2018) <sup>[14]</sup> conducted a simulation study and developed recommended irrigation schedule depending on water deficit analysis using CROPWAT model. They also found that compared to the rainfed control, the two or three times of supplemental water irrigated to sorghum at the right time reduced the loss of yield, under different scenarios. Vashisht and Satpute (2015) <sup>[17]</sup> reported that due to change in critical soil moisture depletion from 20% to 40%, the effective rain efficiency found to increase from 42.9% to 52.2% which in turn resulted in variation of actual crop irrigation water requirement from 321.4 mm to 252.7 mm. Even the model suggested an addition of 253.7 mm of irrigation water at critical crop growth stages in order to realize optimal tomato yields as the crop experienced an irrigation deficiency of 48.8% (Karuku *et al.*, 2014) <sup>[11]</sup>.



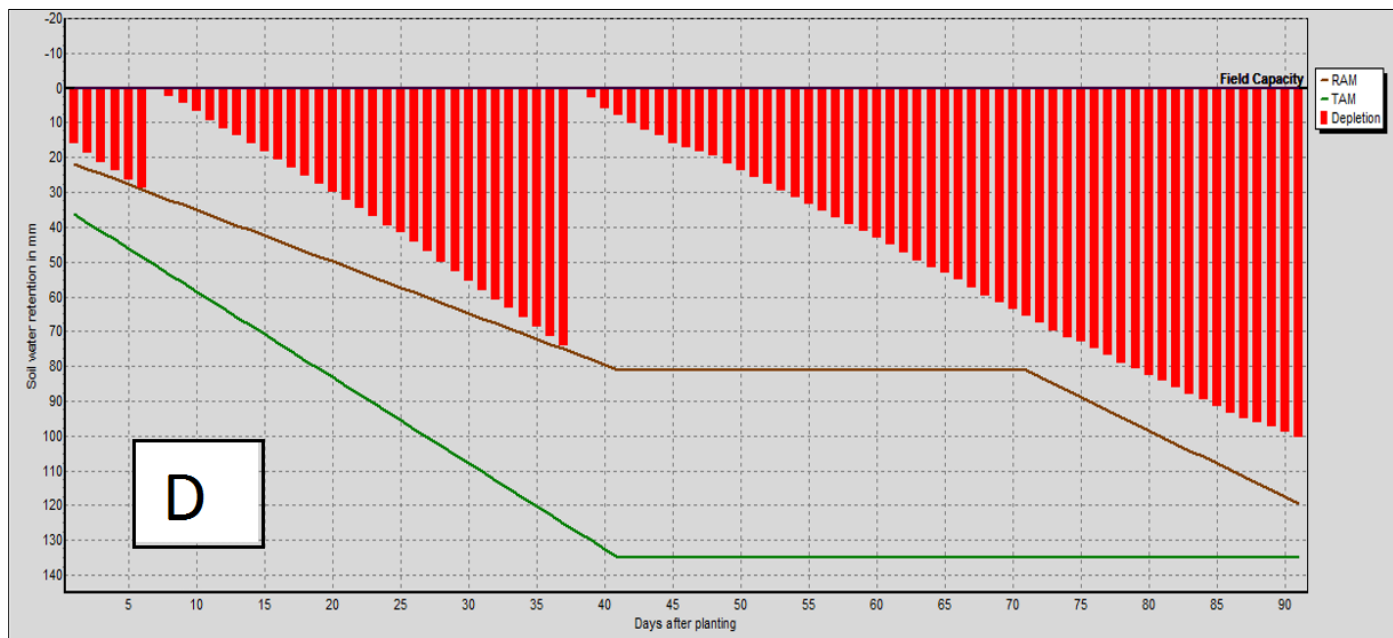


Fig 2: Irrigation scheduling of Field Pea at critical water need stages during *rabi* seasons of 2017-18 (C) and 2018-19 (D)

### Conclusion

The present study gave us the opportunity to compute the actual crop evapotranspiration and total seasonal water requirement of field Pea using CROPWAT simulation well in advance using the real time weather, soil and crop management data. Depending upon these results, two important critical water need stages was identified in new alluvial agro-climatic zone of West Bengal in which supplemental irrigation should be provided under deficit irrigation conditions to prevent the crop failure and maintain optimum crop yield. Estimation of water demand under warming climatic conditions was also made possible which will enable farmers to plan their irrigation schedule to field Pea during *rabi* season in future weather conditions.

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