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Assessment of crop water requirement and irrigation scheduling of potato using weather models under sub temperate climatic condition of North-Western Himalaya

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सार – सिंचाई के पानी को अनुकूलित करने और उपज बढ़ाने के लिए, सिंचाई के पानी की उचित मात्रा और वास्तविक समय के मौसम के आंकड़ों के अनुसार इसका समय-निर्धारण करने से फसल जल फुटप्रिंट को कम करने में मदद मिल सकती है। पिछले कुछ दशकों में अध्ययन क्षेत्रों में बदले हुए जलवायु परिदृश्यों को दर्शाते हुए वर्तमान मौसम की स्थिति का उपयोग करके वाष्पोत्सर्जन (ET) आधारित सिंचाई समय-निर्धारण पानी का विवेकपूर्ण उपयोग साबित हुआ है। 2015-16 के रबी के मौसम के दौरान कृषि विज्ञान विभाग, सीएसके एचपीकेवी, पालमपुर, हिमाचल प्रदेश के अनुसंधान फार्ममें ET आधारित सिंचाई समय-निर्धारण का अध्ययन करने के लिए 20 दिसंबर और 20 जनवरी की बुआई विंडो के तहत चार ET आधारित मौसम मॉडल सिंचाई समय-निर्धारण विधियों अर्थात् बिना सिंचाई या वर्षा आधारित, थॉर्नथवेट, हरग्रीव्स विधि, तापमान और संशोधित पेनमैन मोंटेथ का फील्ड अनुप्रयोग किया गया। उत्तर पश्चिमी हिमालय के अंतर्गत विभिन्न ET अनुमान विधियों के साथ अनुमानित फसल वाष्पोत्सर्जन (ETc) ने फसल के मौसम के दौरान भिन्नता दिखाई। हरग्रीव्स विधि से जनवरी में बोई गई आलू की फसल की तुलना में दिसंबर में उच्चतम अनुमानित ET (376.8 मिमी) देखी गई, इसके बाद तापमान (354 मिमी), थॉर्नथवेट (329.5 मिमी) और संशोधित पेनमैन मोंटीथ विधि (241.9 मिमी) में सबसे कम अनुमानित ET देखी गई। ETC आकलन के अन्य तरीकों की तुलना में पैन वाष्पीकरण से अनुमानित ETC (382.3 मिमी) सबसे अधिक पाया गया। आलू की फसल की पानी की आवश्यकता का अनुमान लगाने के लिए विभिन्न फेनोफ़ेज़ पर तैयार किए गए फसल गुणांक का उपयोग किया गया । यह पाया गया कि ET अनुमान के संशोधित पेनमैन मोंटेथ के आधार पर सिंचाई निर्धारण ने अन्य तरीकों की तुलना में आलू की वृद्धि और कंद उपज को प्रभावित किए बिना फसल अवधि के दौरान 60 मिमी तक एक सिंचाई बचाई; हालाँकि, थॉर्नथवेट विधि पर आधारित सिंचाई निर्धारण में सबसे अधिक आलू कंद उपज (171.76 क्विंटल हेक्टेयर-1) दर्ज की गई है, जो अन्य ET अनुमान विधियों से तैयार सिंचाई निर्धारण के बराबर है। अन्य तरीकों की तुलना में संशोधित पेनमैन मोंटेथ में कुल जल फुटप्रिंट 300 लीटर प्रति किलोग्राम आलू की उपज के हिसाब से सबसे कम थे।

ABSTRACT. To optimize irrigation water and enhance yield, appropriate amount of irrigation water and its scheduling according to real time weather data can help in reducing crop water foot prints. The evapotranspiration (ET) based irrigation scheduling using present weather conditions reflecting changed climatic scenarios in the study regions in the past few decades has proved to be sagacious use of water. To study the ET based irrigation scheduling, field experiment conducted with the treatments comprising four ET based weather models irrigation scheduling methods, *viz.*, no irrigation or rainfed, Thornthwaite, Hargreaves method, Temperature and modified Penman Monteith under sowing windows of 20th December and 20th January were conducted at research farm, of Department of Agronomy, CSK HPKV, Palampur, Himachal Pradesh during Rabi season of 2015-16. The estimated crop evapo-transpiration (ETc) with different ET estimation methods under North Western Himalayas showed variation during crop season. The highest estimated ET was observed in December as compared to January sown potato crop with Hargreaves method (376.8 mm) followed by Temperature (354 mm), Thornthwaite (329.5 mm) and the lowest in modified Penman Monteith methods (241.9 mm).

The estimated ETc from pan evaporation observed to be the highest to the tune of (382.3 mm) compared to other methods of ETc estimation. The crop coefficients modeled at different pheno-phases were used for estimating water requirement of potato crop. It was found that irrigation scheduling based on modified Penman Monteith of ET estimation saved one irrigation to the tune of 60 mm during crop period without affecting significantly growth, and tuber yield of the potato as compared to other methods, *viz*., However, the irrigation schedule based on Thornthwaite method has recorded highest total potato tuber yield (171.76 q ha-1) being at par with irrigation schedules worked out from other ET estimation methods. The total water footprints were the lowest in modified Penman Monteith to the tune of 300 liters per kg of potato yield compared to other methods.

Key words – ET estimation methods, Irrigation scheduling, Potato crop, Sub-temperate climate.

1. Introduction

Water is the most precious natural resource gradually becoming limited resource worldwide and more than one-third of the world population would face absolute water scarcity by the year 2025. The rainfed regions of the world, particularly those with heavy concentrations of population living below the poverty line, are severely impacted by water scarcity. Agriculture is the largest (81%) consumer of water in India and efficient and judicious management of water in agriculture needs to be top most priority (Surendran *et al*., 2013). Alexandratos and Bruinsma (2012) portrayed that agriculture needs to produce 60 percent more food globally by 2050 and 100 percent more in developing countries using the same limited water resources. Estimates for Asia predict about 65 percent increase in industrial water use, a 30 percent increase in domestic use, and a five percent increase in agriculture use by 2030 (Anonymous, 2017). The study clearly indicated decrease of water resources due to changes in climatic conditions in mountains during past three decades (Rana *et al*., 2014). Irrigation is the largest water consuming sector, accounting for more than 80% of the total withdrawals. Rainfall trends in Himachal Pradesh has portrayed decreasing trends (Rana *et al*., 2012). Efficient agricultural water management requires reliable estimation of crop water requirement. For effective decision making in Agriculture, forecasts of weather parameters proved beneficial in saving irrigation in crops (Rana *et al*., 2013).The growing demand for water in agriculture and other sectors, combined with its declining availability in recent decades, highlights the imperative of employing prudent strategies to maximize the use of this limited resource. In crop management, the evapo-transpiration (ET) is considered to be the total water requirement of the crop determines total amount of water in each irrigation. So, employing the methodology for estimation of ET using real time weather observations is important for estimating the crop water requirement.

Potato (*Solanum tuberosum* L.) is one of the most important *Rabi* Vegetable crop with water requirement. India produced about 52.59 million tones potato from an area of 2.18 million ha with an average yield of 24.08 t/ha which contributing 12% of global production (Anonymous, 2019). The crop is very sensitive to water stress and to optimize yields, the total available soil water should not be depleted by more than 30-50 %. Water stress during the growth stages, reduces photosynthetic efficiency and water stress or drought like situation during the periods of tuber initiation and bulking has the most drastic effect on the yield (Lynch *et al*., 1995; Yuan *et al.*, 2003). In Himachal Pradesh, total area under potato crop is 15.87 thousand hectares with a production 199.6 thousand metric tonnes (Anonymous, 2018). The climatic conditions in many parts of the state offer excellent opportunity for producing both disease-free quality seed and table potato. Presently, real time weather database availability has increased and even spatial data is also accessible to end users. Therefore, the study mainly was undertaken focused to optimize crop water requirement with through irrigations scheduling based on real time weather observations.

2. Materials and methods

This study was conducted at research farm of Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur, Himachal Pradesh during *Rabi* season of 2015-16.The experimental site is situated at 32° 06' N latitude and 32° 06' N longitude at an elevation of about 1290.8 m above mean sea level in North-Western Himalaya. The soil of experimental site was silty clay loam in texture, acidic in reaction, medium in available nitrogen (357.12 kg ha^{-1}), medium in available phosphorus (23.6 kg ha^{-1}) and potassium (237.3 kg ha^{-1}). Mild summer and cool winter characterized the climate of study site. May and June are the hottest months, whereas, December and January are the coldest. The weekly minimum and maximum temperature ranged from 14.4 to 32.0 °C and 1.8 to 18.7 °C, respectively. The mean relative humidity ranged between 31.1 to 65.4 percent and total rainfall of 316.6 mm was recorded during the crop period. The cumulative pan evaporation during crop season was 619 mm. The field experimental comprising the four Irrigation scheduling based on ET estimation methods *viz*; (*i*) Modified Penman Monteith (*ii*) Hargreaves method (*iii*) Temperature method (McCloud Equation) (*iv*) Thornthwaite method and to compare weather models one rainfed or no irrigation treatment were tried in two sowing environments during 20th December and 20th

January. The crop coefficients of potato were used as described for sub-temperate conditions by FAO, model validated for local agro-climatic conditions using the crop phenology observed in field. The values of crop coefficients (Kc) so obtained were used to calculate total crop water requirement of crops. Real time rainfall received was also added up in the scheduling calculation using excel calculations for the purpose. The 60 mm irrigation water was used and considered to saturate the soil 100% and further depletion was calculated using different ET based methods. Irrigation was applied when crop evapotranspiration (ET) loss reached on 50%. When there was a cumulative deficit of 30 mm in crop evapotranspiration after the irrigation date, the next irrigation was scheduled for the following day. The precipitation received during the period between irrigations was also taken into account when determining the irrigation schedule. In the rainfed or no irrigation treatment, pre-sowing irrigation was applied to ensure the timely sowing date. The crop observations were taken following standard methodology. The water foot prints per kg of potato were computed using tuber yield.

2.1. *Evapotranspiration Estimation weather models formula used*

2.1.1. *Thornthwaite method. Thornthwaite (1948)*

PET = $1.6(10\ t/I)^a$ (cm $Month^{-1}$).

where,

PET = unadjusted PET (month of 30 days each and 12 hours day time).

t = mean monthly temperature (°C)

I = annual or seasonal heat index and is summation of 12 values of monthly heat indices i

I = $\sum(i)$

I = $(T_{mean}/5)1.514$

a is an empirical exponent and expressed as :

a = $0.000000675\ I^3 - 0.0000771\ I^2 + 0.01792I + 0.49239$.

2.1.2. *Hargreaves method (Hargreaves and Samani, 1985)*

$ET r_o$ = $0.0023 R_A \sqrt{TD}\ (T_{mean} + 17.8)$.

Where;

TD = Difference between mean monthly maximum and mean monthly minimum temperatures in °C.

R_A = is extraterrestrial solar radiation in MJ $m^{-2}\ d^{-1}$,

T_{mean} = mean monthly air temperature in °C.

(*i*) *Temperature method (McCloud, 1955)*

ETp = KW^{T-32}

where;

ETp = Potential evapotranspiration.

K = 0.01

W = 1.07

T = Mean Temperature, °F

2.1.3. *Modified Penman Monteith Method. (Allen et al., 1998)*

For find out the reference crop evapotranspiration is:

ET_o = $W.R_n + (1-W).F(u).(e_a - e_d)$

where,

ET_o = The reference crop evapotranspiration in mm/day (unadjusted).

W = temperature related weighing factor.

R_n = the net radiation in equivalent evaporation in mm/day.

f(u) = the wind related function and given by:

f(u) = $0.27(1+U_2/100)$, U_2 is the wind velocity at 2m height (km^{-1})

$(e_a - e_d)$ = The difference between the saturated vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in m bar.

ed = ea x RH(mean)/100.

TABLE 1

Estimated Reference Evapotranspiration (ET_0) by different models (mm day^{-1}) under varying sowing environments

Month	No Irrigation	Thornthwaite Method	Hargreaves Method	Temperature method (McCloud Equation)	Modified Penman Monteith
			20th December		
December, 2015	1.9	1.81	1.74	1.80	1.05
January, 2016	2.0	1.87	1.82	1.85	1.10
February, 2016	2.3	2.43	2.50	2.39	1.64
March, 2016	2.8	3.25	3.41	3.15	2.18
April, 2016	5.6	4.64	4.92	4.52	3.15
May, 2016	6.8	5.56	5.76	5.36	4.02
Total	**472.4**	**443.9**	**458.97**	**433.31**	**295.49**
			20th January		
January, 2016	2.0	1.87	1.82	1.85	1.10
February, 2016	2.3	2.43	2.50	2.39	1.64
March, 2016	2.8	3.25	3.41	3.15	2.18
April, 2016	5.6	4.64	4.92	4.52	3.15
May, 2016	6.8	5.56	5.76	5.36	4.02
Total	**547.5**	**497.8**	**518.6**	**483.7**	**342.3**

where,

RH = Relative humidity

Rn = Rns-Rnl (mm day^{-1}). (difference between net shortwave solar radiation (Rns) and the net longwave solar radiation (Rnl).

3. Results and discussion

3.1. *Estimated Reference Evapotranspiration (ET_0) by different Methods (mm day^{-1})*

The lowest reference evapotranspiration was estimated in modified Penman Monteith method and whereas the highest evapotranspiration was estimated by Thornthwaite method at the initial crop stagesand subsequently at the later stages of the growth, the highest evapotranspiration was estimated under Hargreaves method. The total ET in December sown potato crop was obtained the highest under Hargreaves method (459 mm) followed by Thornthwaite (444 mm), Temperature (433 mm) and the lowest in modified Penman Monteith (295 mm) (Table 1). While the pan evaporation during crop season recorded to the tune of 472 mm. Similar trend was observed in January sown crop but the magnitude was higher as compared to December sown crop Due to the fact that the January sown crop was exposed more under higher temperature conditions during the reproductive period as compared to December sown crop. However, it was observed during investigation that January and December sown crop took equal number of days to tuber initiation and tuber maturation (141-143 days). Upadhyaya, (2016) also observed that FAO-56 Penman Monteith method to be one of the reliable method of ET_0 estimation using weekly met data under Bihar Conditions. Shreedhar *et al*., (2016) in Western Ghats of India compared five potential estimation evapotranspiration methods for watershed and results revealed the Hargreaves equation of estimation of ET_0 to provide better estimates than the other methods.

3.2. *Estimated crop evapotranspiration (ETc) by different Methods (mm day^{-1})*

The estimated crop evapotranspiration under different treatments have been calculated and presented in Table 2. The crop coefficients (Kc) from FAO for different stages of crop for both sowing dates were used to calculate the stage wise crop ET for estimating crop water requirement of the crop. A close resume of the data

TABLE 2

Estimated crop Evapotranspiration (ETc) by Weather models (mm day^{-1}) under varying sowing environments

Month	No Irrigation	Thornthwaite Method	Hargreaves Method	Temperature method (McCloud Equation)	Modified Penman Monteith
			20th December		
20th -31st December	0.95	0.91	0.87	0.90	0.53
1st-15th January	1.00	0.85	0.91	0.93	0.55
16th-31st January	2.30	1.96	2.10	2.13	1.27
1-29th February	2.65	2.45	2.90	2.75	1.89
1-31st March	3.22	3.45	3.90	3.62	2.51
1-30th April	4.20	3.18	3.7	3.39	2.36
1-31st May	5.10	3.80	4.30	4.02	3.02
Total	**382.32**	**329.52**	**376.82**	**354**	**241.92**
			20th January		
20th -31st January	1.0	0.93	0.93	0.93	0.60
1st-15th February	1.15	1.12	1.12	1.20	0.80
15-29th February	2.65	2.56	2.60	2.75	1.90
1-31st March	3.22	3.50	3.50	3.62	2.5
1-30th April	4.20	3.18	3.20	3.39	2.4
1-31st May	5.10	3.80	3.80	4.02	3.0
Total	**451.92**	**387.13**	**388.33**	**408.02**	**289.6**

TABLE 3

Irrigation scheduling and total ETc in different weather models treatments under varying sowing environments

Methods	Irrigations scheduling interval under different method					No Irrigations	Total ETc
				20th December			
No Irrigation	-	-	-	-	-	**0**	382.0
Thornthwaite Method	28	35	37	13	13	**5**	330.0
Hargreaves Method	28	33	37	13	13	**5**	377.0
Temperature Method (McCloud Equation)	27	36	36	10	14	**5**	354.0
Modified Penman Monteith	44	23	38	21	-	**4**	**242.0**
				20th January			
No irrigation	-	-	-	-	-	**0**	451.9
Thornthwaite Method	38	26	10	15	21	**5**	387.1
Hargreaves Method	39	26	10	15	22	**5**	388.3
Temperature Method (McCloud Equation)	38	27	10	4	20	**5**	408.0
Modified Penman Monteith	60	16	14	18	-	**4**	289.6

TABLE 4

Yield attributes, tuber, biological yield and water footprint in different weather models under varying sowing windows

ET based Irrigation schedulingMethod	Average Tuber weight(gm)	Numberof tubers/plant	Yield q/ha	Biological Yield q/ha	Irrigation water(mm)	Rfmm	Irrigation water+ Rf(mm)	Water footprint (Irrigation)mm	Water footprint Irrigation+ Rf(mm)
Date of sowing									
20th December	34.7	5.57	150.7	163.72	300	212	512	199	339
20th January	31.3	6.20	161.2	174.7	300	250	550	186	342
LSD (P = 0.05)	4.0	0.34	10.1	10.5					
Irrigation scheduling based on ET method									
No Irrigation	28.9	5.17	127.1	138.3	0	231	231	0	182.5
Thornthwaite	35.6	6.00	171.8	186.3	300	231	531	175	309.5
Hargreaves	34.9	6.25	166.0	180.2	300	231	531	181	319.5
Temperature (McCloud Equation)	33.5	6.00	157.6	170.7	300	231	531	190.5	337.5
Modified Penman Monteith	32.0	6.00	157.2	170.6	240	231	471	153	300
LSD (P = 0.05)	4.0	0.53	15.99	16.6					

Rf- Rainfall

revealed that the lowest crop evapotranspiration was estimated in modified Penman Monteith method. The highest crop evapotranspiration was estimated under Temperature method of ET calculation during the initial stages of the crop growth and during the later stages of the growth the highest crop evapotranspiration was estimated in Hargreaves method followed by Thornthwaite method. The total ETc during crop season in December sown crop was observed the highest in Hargreaves method (377 mm) followed by Temperature (354 mm), Thornthwaite (329 mm) and the lowest in modified Penman Monteith methods (242 mm). The pan evaporation observed was the highest to the tune of 382 mm. Similar, trend was observed in January sown crop but the magnitude was higher compared to December sown crop. The reason ascribed to this was one month lag period of maturity of January sown crop which exposed more to higher temperature conditions during the maturation period compared to December sown crop. Penman-Monteith method (Allen *et al*., 1998) used in the study for determining reference crop evapotranspiration (ET_0) and reported to provide values that are very consistent with actual crop water use data worldwide (Lo´pez-Urrea *et al*., 2012). For agro climatic conditions like sub temperate to temperate FAO Penman Monteith ET estimation considered close to the actual ET Jensen *et al*., (1990). Similarly, Basahi, J. M. (2007) also reported Penman Montieth ET estimation is closer when potato crop sown during September to December and January to May. The findings revealed by Rajan, *et al*., (2013) also concluded that Penman Monteith modeling method to estimate the crop water requirement for area at Kancheepuram, Tamil Nadu to be the best as it used the combined climatologically effect of temperature variations and aerodynamic variations.

3.3. *Irrigation scheduling by different weather models under different sowing environments*

The data on irrigation scheduling based on different ET weather models have been given in Table 3. A look at the data revealed that irrigation scheduling using modified Penman Monteith of ET estimation reduced one irrigation to the tune of 60 mm during crop period as compared to irrigation schedules by using other methods *viz*; Hargreaves method, Temperature method and Thornthwaite method of ET estimation (Table 3). The reduced irrigation did not affect the tuber yield; growth attributes yield and tuber yield of the potato under sub temperate conditions of Himachal Pradesh. The modified Penman Monteith of ET estimation reduced the irrigation number to four irrigations compared to 5 irrigations schedules from other methods. Therefore, results clearly portrayed that modified Penman Monteith method of ET estimation using real time weather observations to be the best in saving irrigations and reduced water foot prints by providing irrigation in judicious and precise manner to the crop.

3.4. *Total evapotranspiration, rainfall and effective rainfall*

The data presented in Table 3 revealed that crop evapotranspiration values were lower in December sown crop than January sown crop and the lowest obtained in modified Penman Monteith as compared to other methods. The total rainfall was higher in January sown crop (260.2 mm) compared to December sown crop (209.8 mm). The effective rainfall was 83 % in December and 88 % in January sown crop which might have reflected in total crop water requirement whereas the results also indicated that total contribution of rainfall (Green Water) in total water requirement of potato varied from 57 to 51 %. Similar studies revealed that blue-water footprint contributed more than 75% of the total water requirement and the remainder came from the green-water footprint in potato crop under Egypt agroclimatic conditions in winter potato crop. (Abdel-Hameed *et al.*, 2022. The studies on crop water requirement conducted by Nithya *et al.*, (2016) for selected crops in Karnataka revealed that ET_0 of potato was 318.5 mm/ month while effective rainfall and irrigation requirement was 176.5 mm/month and 210.9 mm/ month, respectively.

3.5. *Yield attributes tuber and biological yield, and water footprint in different weather models under varying sowing windows*

The data presented in Table 4 revealed that water footprint were statistically similarly in January (342 liters water per kg potato) as compared to December sown crop (339 liters/kg potato yield. Amongst different refence evapotranspiration estimations models-based irrigation scheduling, the lowest water requirement (rainfall + irrigations) observed to the tune 300 mm for producing 157.2 q/ha potato yield using modified Penman Monteith method without losing significantly tuber yield, biological yield and tuber weight in winter season. The Temperature method Macleod equation method used the highest amount of water to the tune of 337.5 liters to produce one kg of potato without having statistically significant additional yield advantage when total rainfall received during the crop period was 209.8 mm in December sown crop and 260.2 mm in January sown crop. Similarly, the studies conducted by Rodriguez *et al.*, (2015) under Argentina agroclimatic conditions revealed water footprint of winter season potato to the tune of 323.99 m^3/t.

However, the lowest water foot prints of 182.5 litre/kg potato were obtained in no irrigation treatment with statistically significantly lower potato yield. The crop water requirement of early sown crop during October under Terai region of Uttarakhand was higher than late sown crop during November due to delay in maturity and water loss through evaporation at maturity (Vishnoi *et al.*, 2012).

4. Conclusions

Based on the study's findings, it was concluded that employing modified Penman Monteith method for estimating evapotranspiration (ET) and utilizing real-time weather data is the most effective approach for irrigation scheduling, resulting in the potential saving of one irrigation event (60 mm), in comparison to other methods of ET estimation. Therefore, under Sub temperate agro-climatic conditions in Himachal, the modified Penman Monteith method using real-time weather data proved to reduce crop water requirement and irrigation schedules without affecting the biological yield, tuber yield, number of tubers, and average tuber weight, as evidenced statistically. Such findings would serve as a significant milestone for the advisory work of Gramin Krishi Mausam Sewa.

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