GMR

The Original

PHENOLOGICAL RESPONSE OF POTATO CULTIVARS TO AGROMETEOROLOGICAL INDICES ACROSS DIVERSE GROWING ENVIRONMENTS IN NORTH-WESTERN PLAINS OF INDIA

Rajesh Kumar*[1], Chander Shekhar Dagar[2], Anil Kumar[3], Mohit Kamboj[4], Sultan Singh[5], Monika Yadav[6], Satinder Singh[7]

[1*]Chaudhary Charan Singh Haryana Agricultural University, Krishi Vigyan Kendra, Jind-126102, Haryana, India,
Email id:- sainirajeshagmhau@gmail.com
[2,3]Department of Agricultural Meteorology, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125004, Haryana, India
[4,5]Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala-133207, Haryana, India
[6]Maharana Pratap Horticultural University, Karnal-132001, Haryana, India
[7]Department of Business Management, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana-125004, India

ABSTRACT
The study was conducted during the Rabi season of 2019–20 and 2020–21 at Chaudhary Charan Singh Haryana Agricultural University, Haryana Agricultural University, Hisar, to evaluate the thermal indices such as Growing Degree Days (GDD), Helio-thermal Units (HTU), Photo-thermal Units (PTU), thermal use efficiency (TUE) and radiation use efficiency (RUE) of different potato varieties viz. V1- Kufri Bahar, V2- Kufri Pushkar and V3- Kufri Lima under different planting dates viz. D1- 10th October, D2- 25th October, D3- 10th November and D4- 25th November. The results revealed that D1 sown crop recorded highest AGDD (1237.1°C days), AHTU (5833.3°C day hours), APTU (13646.4°C day hours), D4 sown crop recorded highest TUE (0.16 gm-2 °C days) and the maximum RUE was found in D2 sown crop i.e. 0.65 g MJ-1during crop season 2019-20 whereas, in 2020-21, D1 recorded highest AGDD (1130.9°C days), APTU (12420.6°C day hours), D4 recorded highest AHTU (5978.8°C day hours), D2 sown crop recorded highest TUE (0.23 gm-2 °C days) and RUE (1.59 g MJ-1). Among different varieties, Kufri Lima accumulated maximum AGDD (1002.5°C day and 1068.5°C days), AHTU (4062.1°C day hours and 5806.7°C day hours), APTU (11003.6°C day hours and 11716.9°C day hours), the maximum TUE and RUE was observed in Kufri Pushkar (0.16 gm-2 °C days and 0.21 gm-2 °C days) and (0.54 g MJ-1 and 1.37 g MJ-1) respectively, during both the crop seasons. The findings show the importance of selecting an optimum planting time and variety for maximizing potato yield. This becomes especially relevant in the context of increasing climate variability in semi-arid regions and north-western plains of India.

KEYWORDS: Climate, Variability, Optimum, Planting Time, Potato, GDD, RUE, TUE

1. INTRODUCTION

Potato (Solanum tuberosum L.) is inherently a temperate crop but has become a major staple food crop around the world. It is the third most important food crop in the world after rice and wheat and plays an important role in food and nutritional security (International Potato Center, 2018). Its importance is not restricted to direct consumption alone. It is also a raw material for value added products like chips, alcohol, glucose and starch. In India, the cultivation of potato crop is done in an area of about 22.50 lakh ha with a production of 536.87 LMT and an average productivity of 23.3 t ha^{-1} (Anonymous, 2021). But in Haryana, the crop is cultivated in a relatively smaller area of 0.307 lakh ha, but has a higher productivity of 26.26 t ha^{-1}, which shows the favourable agronomic and climatic conditions for potato cultivation in the region (Anonymous, 2021).

Environmental factors, especially temperature, radiation and soil moisture, markedly affect the growth, development and yield potential of the potato crop. The crop prefers cool climates with an optimum mean daily temperature of 18–20°C for maximum tuber production. Growth of tubers is greatly inhibited when temperatures are below 10 °C or above 30 °C and exposure to either frost or extreme heat can seriously damage the crop (Haverkort 1990; Hijmans et al., 2003; Monneveux et al., 2014). In addition, potatoes are sensitive to photoperiod and thermal time, for vegetative growth it requires long-day conditions whereas for tuberization it requires short-day conditions (Chadha, 2009).

Understanding and quantifying the response of the crop to thermal and solar energy inputs is important to optimize its productivity under different climatic conditions. Thermal indices such as Growing Degree Days (GDD), Helio-thermal Units (HTU) and Photo-thermal Units (PTU) are used to assess the accumulation of heat required for different phenophases of the crop. These indices help in predicting crop development, scheduling agricultural operations, and identifying stress periods during the crop lifecycle (Salack et al., 2015; Ahmadi et al., 2019). Additionally, Thermal Use Efficiency (TUE) and Radiation Use Efficiency (RUE) are key measures that indicate how efficiently the plant utilizes the absorbed thermal and radiation energy to produce dry matter and yield (Asseng et al., 2015; Salack et al., 2015). These efficiencies vary depending on the cultivar, environmental conditions, and, importantly, the time of planting.

The time of planting is a critical agronomic factor that directly controls the exposure of the crop to the prevailing temperature and radiation regimes. Potato sown at the right time experiences the best microclimatic conditions for better light interception, canopy expansion and dry matter partitioning leading to higher tuber yield (Ezekiel et al., 1997; Kumar et al., 2019). However, delayed planting may reduce the effective growing period by exposing the crop prematurely to suboptimal temperatures, resulting in reduced biomass accumulation and yield (Sanwal et al., 2003). Earlier research by (Patel et al., 2000; Sanwal et al., 2003; Patel et al., 2000; Samanta et al., 2020) also supports the concept of selecting the optimum planting window significantly enhances radiation use efficiency and yield stability. The third week of October is optimum period for potato development in semi-arid agro-climatic zone of Haryana as it is free from early season heat and late season frost (Ahmadi et al., 2019).
In this regard, the assessment of the thermal and radiation use efficiencies of potato under different planting dates becomes crucial, particularly in the context of increasing climate variability. Studies on temperature and radiation individually affecting potato growth are many but few attempts have been made to quantify the energy-use efficiencies of the crop response in real field conditions across multiple planting windows in Haryana. Such studies can aid farmers in choosing the optimal time of sowing and best variety for maximizing the conversion of environmental energy into economic yield.

MATERIALS AND METHODS

A field experiment was carried out during Rabi seasons of 2019-20 and 2020-21 at the Research Farm of Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar. This location is situated at latitude 29°10'N, longitude 75°46'E with an elevation of 215.2 m above mean sea level. The site has a semi-arid subtropical climate with cool winters, temperature extremes and occasional frost events suitable for studying the effects of thermal regimes on potato. The soil of the experimental site was sandy loam, neutral in pH (8.1), with EC 0.68 dSm-1 and 0.43% organic carbon. The experiment was conducted in Factorial Randomized Block Design (FRBD) with four replications, Four planting dates (D1-10th October, D2-25th October, D3-10th November and D4- 25th November) and Three potato varieties (Kufri Pushkar, Kufri Bahar, Kufri Lima).
Standard agronomic practices were applied across all plots. Data on crop phenology, canopy temperature, LAI, dry matter, and yield were collected at key growth stages.
Daily weather data were recorded using an automatic weather station.
The following thermal and radiation indices were computed:
Growing Degree Days (GDD)

$$\text{GDD (°Cday)} = \sum \frac{(\text{Tmax}+\text{Tmin})}{2} - \text{Tbase} \qquad \text{(Eqn. 1)}$$

Where, T base = 50C for potato

2. Helio-thermal Units (HTU)

Helio-thermal units (HTU) = ∑ (GDD x BSS) (Eqn. 2)

3. Photo-thermal Units (PTU)

Photo-thermal units (PTU) = ∑ (GDD x N) (Eqn. 3)

4. Thermal Use Efficiency (TUE)

$$\text{TUE } (\text{g/m}^2/\text{°Cday}) = \frac{\Sigma \text{ biomass production } (\text{g/m}^2)}{\Sigma \text{ Growing degree days (°C day)}} \qquad \text{(Eqn. 5)}$$

5. Radiation Use Efficiency (RUE)

Radiation use efficiency is determined by ratio of biomass yield in g/m2 to the accumulated IPAR

$$\text{RUE (g/MJ)} = \frac{\Sigma \text{ biomass production } (\text{g/m}^2) \text{ during30 days interval}}{\text{Cumulative IPAR } (\text{MJ/m}^2) \text{ during 30 days interval}}$$

Daily solar radiation was computed by the expression
Rs = Ra (1-r) (a+b (n/N)
Where,
Rs is solar radiation received at the surface of the earth (cal/cm2)
Ra is solar radiation received outside the atmosphere (cal/cm2) used from Smithsonian tables corresponding to the latitude values of Hisar
r is reflection coefficient (0.25) for green vegetations
a and b are constants [a= 0.256; b = 0.56 for Hisar,
Daily PAR was calculated by the formula:
PAR = Rs x 0.48
The PAR values were converted into MJ/m2. The daily IPAR was calculated using the following expression:
IPAR= PAR (1-e-kf) (Rosenthal and Gerik, 1991).

Where,
k is extinction coefficient = ln (I-Io)/F,
f is cumulative leaf area index of foliage layer,
Io is radiation energy at the top of the canopy,
I is radiation energy at a level inside the crop canopy.

The data was analysed statistically using analysis of variance (ANOVA) as applicable to Factorial RBD design. The F-test with a 5% probability was used to measure the significance of the treatment effects. The critical difference (C.D.) was calculated to determine whether there was a significant difference between the means of two treatments.

6. RESULTS AND DISCUSSION

Accumulated Growing Degree Days (°C days)

The Accumulated Growing Degree Days (AGDD) increased progressively with the advancement of crop phenophases across all treatments during both years. In 2019–20, the highest AGDD to reach physiological maturity was recorded in D1 (15 Oct) sown crop (1237.1°C days), followed by D2 (980.8°C days), D4 (844.4°C days), and lowest in D3 (792.4°C days). Similarly, during 2020–21, D1 again required the highest AGDD (1130.9°C days) to attain maturity, while D2, D3, and D4 showed closely spaced but lower AGDD values ranging between 981.8°C days to 998.1°C days.

The reduction of AGDD for the late planting of potatoes (D3, D4) at critical developmental stages such as tuber initiation and subsequently bulking points to faster phenological development due to the presence of relatively cooler thermal regimes, and thus the effective growing season duration becomes shorter. Conversely, earlier planting (D1) appears to prolong the vegetative and bulking stage in the case of relatively warmer temperatures, implying that the plant would need to accumulate more thermal units. Such variations were indeed significantly different for the phenological stages as well as between the years of cultivation. In case of cultivars, Kufri Lima appeared to demand the maximum number of AGDDs (1002.5°C days & 1068.5°C days) to attain physiological maturity during both years.

This signifies a greater period and also higher thermal demand; after that, came Kufri Pushkar and thereafter, Kufri Bahar. The variability in the GDD formation amongst varieties is an indication of the variations in the natural growth period and thermal sensitivity, consistent with findings of (Ahmadi et al.,2019; Kumar et al., 2019). Whole results really prove the fact that thermal time accumulation is a reliable indicator for the development of the crop. In addition, the date of planting has a significant influence on the interception and use of thermal units by the crop. Early planting, to some extent, is compatible with favourable thermal regimes; it increases the growth period and helps in accumulating more dry matter. Delayed planting accelerates the phenological development under less favourable thermal regimes; hence reducing energy-use efficiency.

Accumulated Helio Thermal Units (°C day hours)

The Accumulated Helio-Thermal Units (AHTU), calculated as a product of Growing Degree Days (GDD) multiplied by the recorded sunshine hours, progressively increased with each subsequent stage of crop growth in all cases considered. In 2019–20, the maximum value of AHTU in physiological maturity period belonged to D1-sown crop (5833.3°C day hours), followed by D4 (4343.8°C day hours), D2 (3800.5°C day hours), and D3 (3383.7°C day hours), respectively. However, during 2020–21, some shift occurred D4 was characterized by the maximum value of AHTU (5978.8°C day hours), while D1 had the second maximum one (5937.5°C day hours) and the minimum in D2 (4909.7°C day hours). Such fluctuations in the values of AHTU depending on crop planting dates could be explained by the change in the sunshine duration, alongside with the thermal resource, during the growth of the plant. The high values of AHTU registered in the crops of D1 and D4 planting dates indicated that they were exposed to longer sunlight duration or had prolonged growth phase which helped to accumulate more helio-thermal energy. As for low values of AHTU registered in D2 and D3 crops, it indicated the lack of sunshine duration or reduced growth period.

Amongst the varieties studied, Kufri Lima was the most efficient as per its higher values of AHTU of 4062.1°C day hours and 5806.7°C day hours in 2019–20 and 2020–21 respectively, after which were Kufri Pushkar and Kufri Bahar. This kind of variation shows the presence of genetic variability in crop duration as well as canopy characteristics. It appears that Kufri Lima gets a better return due to the increased solar exposure in critical growth phases. Helio-thermal energy is an important aspect affecting the yield and performance of a particular variety, particularly when there is a change in the planting period. (Kumar et al., 2019; Salack et al., 2015). Thus, in general, this research has essentially highlighted the fact that both the timing of planting and variety selection determine the efficiency of utilization of Helio-thermal energy in potatoes.

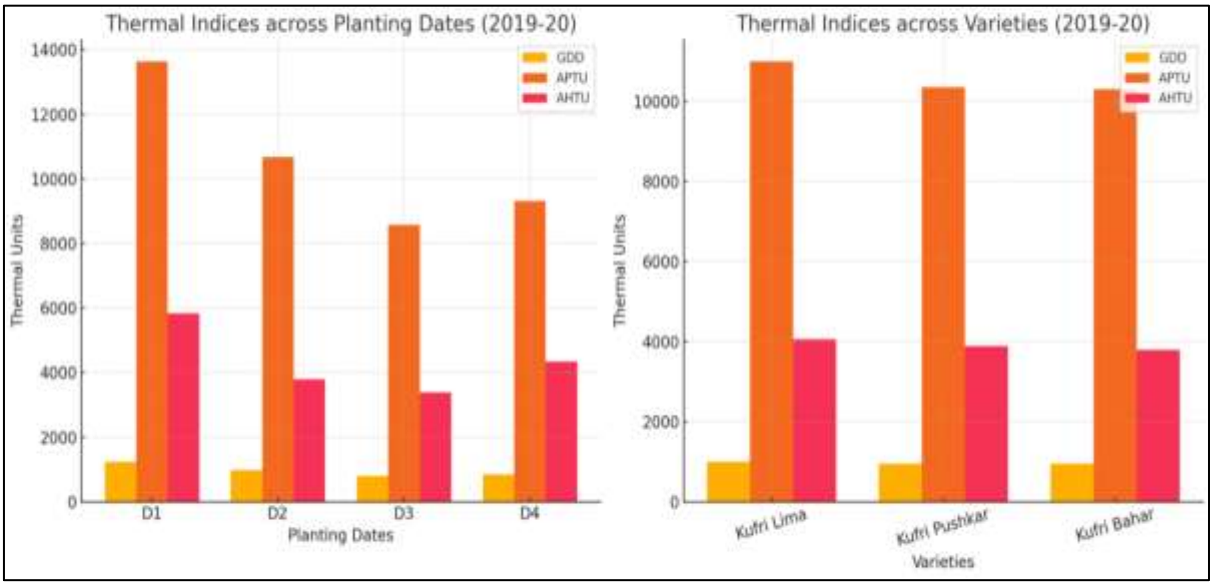
Accumulated Photo-thermal Units (APTU, °C day hours)

The Accumulated Photo-thermal Units (APTUs) include thermal time and photoperiod that is day length and increased progressively as the plants developed irrespective of the treatments. Furthermore, there were very distinct differences between planting dates and varieties during the two seasons. In the first season, the maximum APTUs for physiological maturity were recorded for the D1 (15 October) planted crop (13646.4°C day hours). Second highest APTUs were for D2 (10678.3°C day hours), followed by D4 (9315.2°C day hours) and the minimum APTUs were for D3 (8579.7°C day hours). There was a similar trend in 2020-21 where the highest APTUs were for D1 (12420.6°C day hours) and the minimum APTUs were for D3 (10764.5°C day hours).

It is fairly simple to explain the reason for increased APTU in early sowing dates, which was due to the longer duration of the crop in the field and favourable thermal and photoperiodic conditions at the important developmental stages such as tuber bulking and maturity. On the other hand, late sowing (D3 and D4), which was characterized by short days and lower temperature, accelerated the crop development rate resulting in reduced APTU accumulation. This means that later sowing may reduce the duration of crop growth period, thus reducing thermal and light integration for biomass production. Considering cultivars, Kufri Lima continued to display the highest values of APTU to become mature (11003.6°C day hours and 11716.9°C day hours during 2019–20 and 2020-21, respectively). Following this were Kufri Pushkar and Kufri Bahar.

It is clearly seen from the results obtained that the accumulation of Photo-thermal energy can be used as a dependable predictor of the rate of development of potatoes, and picking the right moment for sowing is extremely important for using solar and thermal energy to the maximum degree.

Fig. 1:



Comparison of Thermal Indices (GDD, APTU, AHTU) Across Planting Dates and Potato Varieties During Rabi 2019–20.

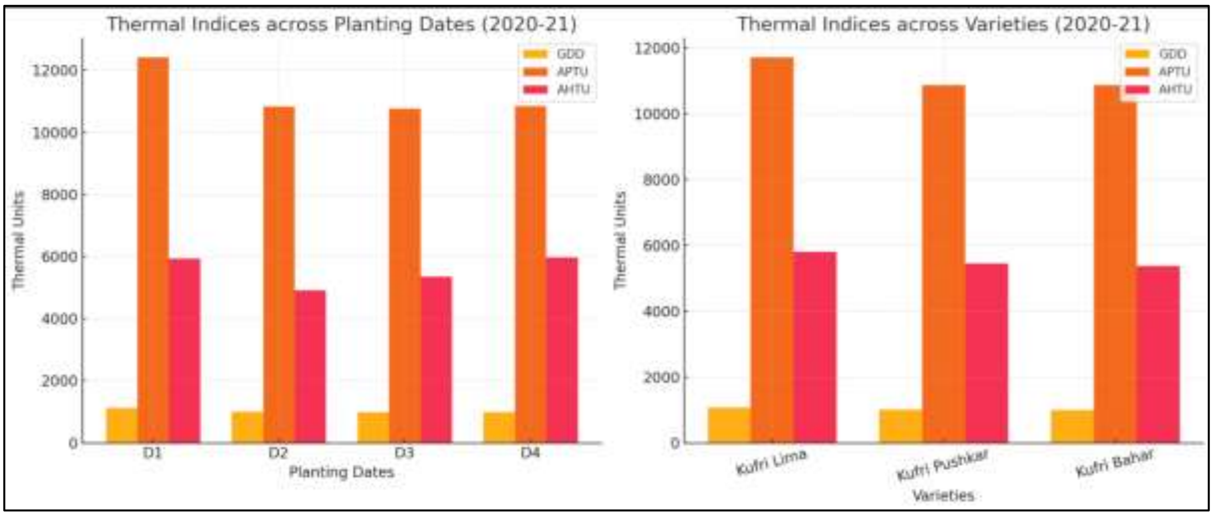


Fig. 2: Comparison of Thermal Indices (GDD, APTU, AHTU) Across Planting Dates and Potato Varieties During Rabi 2020–2021.

(In D1 seems like the greatest thermal build up shows up in all categories across the different planting dates and, Kufri Lima kind of keeps being the top performer, with the uppermost thermal indices among the varieties during both seasons, without a lot of change.)

Thermal Use Efficiency (TUE, g m-2 °C day)

Thermal Use Efficiency (TUE), measured as grams of tuber yield per unit of accumulated Growing Degree Days (GDD), displayed different patterns in dependence on planting date and variety throughout both growing seasons. It differed greatly between different combinations. The highest values of TUE were recorded for the case of D2 planting date (22 October), for practically all tested varieties. It indicates that there was better synchronisation of the crop growth phases with the ambient thermal regime at that moment. However, the use of D4 planting date (5 November) resulted in the lowest value of TUE. This effect was mainly caused by the decrease in thermal availability for bulking and maturity processes.

There is a reason why the D2 planting date performed better. The point is that there is an influence of the thermal regime on the critical period of bulking. Consequently, accumulation of dry matter was more efficient, and TUE became higher. Despite the increase in accumulated heat in case of D1 planting date, TUE remained low. It can be explained by the fact that at the beginning of the season high temperatures made the process of vegetation faster, and assimilates transportation to tubers became inefficient.

For different types, Kufri Pushkar maintained its dominance in both the years in TUE, followed by Kufri Lima and Kufri Bahar. Kufri Pushkar had longer bulking period and higher proportion of dry matter partitioning in tubers, hence thermal efficiency remained higher. This is in agreement with (Darabi et al., 2020; Kumar et al., 2019), according to whom thermal use efficiency is a variety specific trait and is highly related to varietal thermal response and growth duration. Hence, overall third week of October is the best for planting, particularly Kufri Pushkar, to take advantage of thermal resources.

Radiation Use Efficiency (RUE, g MJ-1)

Radiation Use Efficiency (RUE), which represents the ratio of the tuber yield and intercepted Photosynthetically Active Radiation (PAR), was found to vary significantly among planting dates and genotypes in both seasons of cultivation. Maximum RUE was observed in case of D2 planting (22 October), in all cases consistently among genotypes, whereas the minimum RUE was recorded for D4 (5 November) sown crops.
This type of pattern, essentially, indicates a superior canopy development and radiation capture during the active vegetative and bulking period of D2 planting, leading to higher efficiency of converting the incoming solar energy into biomass. In comparison, lower RUE of the D4 planting is attributed to the shorter day length and lower availability of the solar radiation for interception and subsequent conversion into biomass. Further, RUE in case of early planting D1 is slightly lesser than D2 due to sparse canopies and higher respiration during the initial growth phase.
In terms of the cultivars, it is observed that the highest value of RUE is found in Kufri Pushkar followed by Kufri Lima and Kufri Bahar. This may be due to the reason that Kufri Pushkar might have enjoyed high LAI and the duration for radiation interception leading to greater dry matter production and hence tuber yield per unit of absorbed radiation. These results are supported by (Kumar et al., 2019; Samanta et al., 2020). Also, reported cultivar-specific differences in RUE under varying Photo-thermal environments.
Thus, it can be concluded that growing potatoes in the third week of October in case well-performing cultivars like Kufri Pushkar are grown shall be ideal in terms of solar energy utilization and tuber yield in the agro-climatic condition of Haryana.

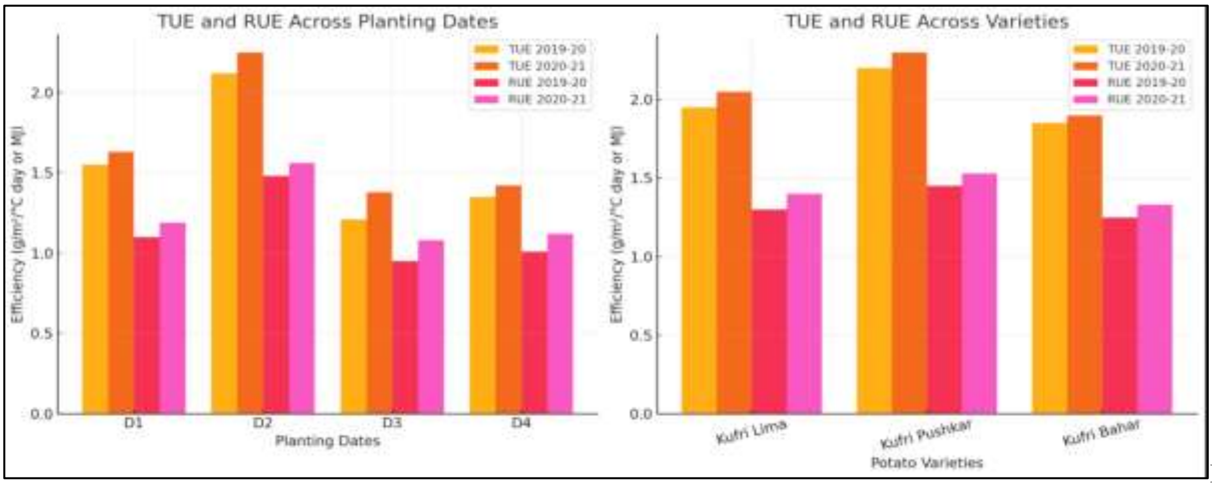


Fig. 3: Thermal and Radiation Use Efficiencies (TUE, RUE) of Potato Across Planting Dates and Varieties During Rabi 2019–20 and 2020–21

(*This visual clearly shows how mid-October planting (D2) and Kufri Pushkar consistently perform best in terms of energy use efficiency)

Table 1: Effect of planting dates and varieties on the Accumulated Growing Degree Days (AGDD, °C day) at various phenophases in potatoes during 2019-20 and 2020-21

Treatment	2019-20					2020-21				
	Phenophases									
	Emergence/ Sprout development	Stolonization	Tuber initiation	Tuber bulking	Physiological maturity	Emergence/ Sprout Development	Stolonization	Tuber initiation	Tuber bulking	Physiological Maturity
Factor A (Planting dates)										
D1(10th Oct)	292.0	608.1	864.6	1042.7	1237.1	329.0	433.6	635.0	750.0	1130.9
D2(25th Oct)	268.4	540.1	735.4	807.9	980.8	276.3	379.3	550.0	625.9	998.1
D3(10th Nov)	240.7	440.3	531.3	625.1	792.4	218.1	396.3	523.7	587.2	986.3
D4(25th Nov)	203.7	316.2	416.6	491.2	844.4	190.2	244.9	361.2	416.5	981.8
SE(m)	1.52	1.15	1.00	0.70	1.49	2.09	2.11	1.41	1.17	2.01
CD(A) at 5%	4.41	3.33	2.89	2.01	4.29	6.04	6.09	4.06	3.39	5.97
Factor B (Varieties)										
V1(Kufri Bahar)	237.9	466.7	629.9	734.7	942.4	235.3	342.3	492.8	569.6	993.0
V2(KufriPushkar)	251.7	476.4	636.8	741.7	946.1	251.3	352.8	513.3	592.2	1011.3
V3 (Kufri Lima)	264.0	485.4	644.2	748.7	1002.5	273.6	395.6	546.3	622.9	1068.5
SE(m)	1.32	1.00	0.87	0.60	1.29	1.81	1.82	1.22	1.02	1.79
CD (B) at 5%	3.82	2.88	2.50	1.74	3.72	5.23	5.27	3.52	2.94	5.17

Table 2: Effect of planting dates and varieties on the Accumulated Helio Thermal Unit (AHTU, °C day hours) at various phenophases in potatoes during 2019-20 and 2020-21

Treatment	2019-20					2020-21				
	Phenophases									
	Emergence/ Sprout Development	Stolonization	Tuber initiation	Tuber bulking	Physiological Maturity	Emergence/ Sprout Development	Stolonization	Tuber Initiation	Tuber bulking	Physiological Maturity

Factor A (Planting dates)										
D1 (10th Oct)	2179.1	3594.6	4435.3	5142.5	5833.3	2180.3	2771.1	3424.4	4139.6	5937.5
D2 (25th Oct)	1058.9	2114.3	2832.1	3053.6	3800.5	1226.2	1665.7	2763.4	3166.4	4909.7
D3 (10th Nov)	927.9	1527.9	1913.2	2200.7	3383.7	1028.3	2097.6	2606.2	2770.1	5352.1
D4 (25th Nov)	797.5	1057.6	1397.9	1853.1	4343.8	1218.3	1551.0	1911.5	2069.2	5978.8
SE(m)	9.20	5.58	3.20	4.67	11.59	11.93	12.75	7.75	6.49	14.04
CD (A) at 5%	26.59	16.14	9.25	13.49	33.50	34.47	36.83	22.39	18.74	40.58
Factor B (Varieties)										
V1 (Kufri Bahar)	1181.1	2080.5	2628.6	3026.1	3789.5	1329.6	1890.3	2586.4	2893.9	5369.2
V2 (Kufri Pushkar)	1235.8	2109.5	2642.1	3063.8	3890.8	1415.4	1960.3	2649.8	3022.5	5457.7
V3 (Kufri Lima)	1305.6	2132.3	2663.1	3097.5	4062.1	1494.7	2213.5	2792.9	3192.6	5806.7
SE(m)	7.97	4.84	2.77	4.04	8.28	10.33	11.04	6.71	5.62	12.16
CD (B) at 5%	23.03	13.98	8.01	11.68	23.93	29.85	31.90	19.39	16.23	35.14

Table 3: Effect of planting dates and varieties on Accumulated Photo Thermal Unit (APTU, °C day hours) at various phenophases in potatoes during 2019-20 and 2020-21

Treatment	**2019-20**					**2020-21**				
	Phenophases									
	Emergence/ Sprout Development	**Stolonization**	**Tuber initiation**	**Tuber bulking**	**Physiological Maturity**	**Emergence/ Sprout Development**	**Stolonization**	**Tuber Initiation**	**Tuber bulking**	**Physiological Maturity**
Factor A (Planting dates)										
D1 (10th Oct)	3349.2	6878.9	9659.7	11560.4	13646.4	3752.5	4912.3	7114.1	8351.5	12420.6
D2 (25th Oct)	3000.2	5952.1	8037.2	8808.5	10678.3	3056.3	4172.3	6001.4	6809.9	10836.9
D3(10th Nov)	2614.5	4747.4	5710.2	6726.2	8579.7	2360.7	4260.4	5617.1	6299.5	10764.5
D4(25th Nov)	2179.3	3377.1	4459.2	5261.5	9315.2	2031.4	2607.2	3853.3	4453.5	10853.2
SE(m)	17.07	12.54	10.50	6.53	16.40	22.76	22.39	15.00	12.87	23.84
CD (A) at 5%	49.33	36.24	30.35	18.86	47.38	65.78	64.71	43.36	37.19	68.88
Factor B (Varieties)										
V1(KufriBahar)	2638.8	5136.5	6892.1	8017.5	10308.3	2601.0	3759.6	5382.5	6205.6	10867.6
V2(KufriPushkar)	2791.7	5241.5	6966.7	8080.8	10352.9	2777.7	3873.1	5601.9	6452.6	11071.8

V3 (Kufri Lima)	2927.0	5338.7	7041.0	8169.1	11003.6	3022.0	4331.5	5955.0	6777.6	11716.9
SE(m)	14.78	10.86	9.10	5.65	14.20	19.72	19.39	12.99	11.14	20.64
CD (B) at 5%	42.72	31.39	26.29	16.33	41.03	56.97	56.04	37.55	32.20	59.65

Table 4: Effect of planting dates and varieties on Thermal Use Efficiency (TUE, g m-2 °C day) at various phenophases in potatoes during 2019-20 and 2020-21

Treatment	**2019-20**					**2020-21**				
	Phenophases									
	Emergence/ Sprout Develoment	**Stolonization**	**Tuber initiation**	**Tuber bulking**	**Physiological Maturity**	**Emergence/ Sprout Develoment**	**Stolonization**	**Tuber Initiation**	**Tuber bulking**	**Physiological Maturity**
Factor A (Planting dates)										
D1(10th Oct)	0.03	0.05	0.08	0.10	0.11	0.03	0.09	0.14	0.16	0.13
D2(25th Oct)	0.04	0.07	0.10	0.15	0.15	0.05	0.12	0.18	0.23	0.17
D3(10th Nov)	0.02	0.07	0.12	0.14	0.15	0.03	0.09	0.15	0.18	0.14
D4(25th Nov)	0.02	0.05	0.10	0.12	0.16	0.03	0.09	0.18	0.20	0.11
SE(m)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CD (A) at 5%	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.002	0.001
Factor B (Varieties)										
V1(KufriBahar)	0.03	0.06	0.09	0.12	0.13	0.03	0.09	0.15	0.18	0.12
V2(KufriPushkar)	0.03	0.07	0.11	0.13	0.16	0.04	0.11	0.18	0.21	0.15
V3(Kufri Lima)	0.03	0.06	0.10	0.12	0.14	0.03	0.09	0.16	0.19	0.13
SE(m)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CD (B) at 5%	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001

Table 5: Effect of planting dates and varieties on Radiation Use Efficiency (RUE, g/MJ) at various phenophases in potatoes during 2019-20 and 2020-21

Treatment	**2019-20**	**2020-21**
	Phenophases	

	Emergence/ Sprout Development	Stolonization	Tuber initiation	Tuber bulking	Physiological maturity	Emergence/ Sprout Development	Stolonization	Tuber initiation	Tuber bulking	Physiological Maturity
Factor A (Planting dates)										
D1 (10th Oct)	0.13	0.28	0.39	0.47	0.46	0.15	0.54	0.85	1.00	0.83
D2 (25th Oct)	0.27	0.36	0.49	0.65	0.60	0.38	0.89	1.21	1.59	0.92
D3 (10th Nov)	0.10	0.32	0.44	0.53	0.50	0.25	0.58	1.07	1.21	0.65
D4 (25th Nov)	0.13	0.18	0.37	0.42	0.40	0.20	0.60	1.27	1.27	0.45
SE(m)	0.004	0.003	0.003	0.003	0.003	0.006	0.008	0.005	0.006	0.008
CD (A) at 5%	0.011	0.008	0.01	0.008	0.008	0.017	0.022	0.015	0.018	0.022
Factor B (Varieties)										
V1 (Kufri Bahar)	0.15	0.26	0.40	0.48	0.45	0.23	0.59	1.02	1.21	0.65
V2 (Kufri Pushkar)	0.18	0.32	0.46	0.54	0.50	0.28	0.75	1.20	1.37	0.79
V3 (Kufri Lima)	0.14	0.27	0.41	0.50	0.47	0.23	0.62	1.09	1.23	0.69
SE(m)	0.003	0.002	0.003	0.002	0.002	0.005	0.007	0.004	0.005	0.007
CD (B) at 5%	0.01	0.007	0.009	0.007	0.007	0.014	0.019	0.013	0.016	0.019

CONCLUSION

It can be observed from the above study that both the date of planting as well as the variety of crops planted have significant effect on the efficiencies of thermal and radiation energy in potato production in the semi-arid climate of Haryana. Among all the planting dates, third week of October (D2) was found to be the best planting date due to its higher TUE and RUE, besides also having optimum GDD, APTU and AHTU during the crop's critical phenophases.

While the earliest planting date (D1) had the maximum thermal indices, its efficiency was a little low because of heat stress at early part of the season. With the delay in sowing (D3 and D4), the thermal as well as radiation environment was less than favorable; thus, resulting in faster phenological development as well as lower dry matter accumulation. Among the varieties studied, Kufri Pushkar was more efficient than Kufri Lima and Kufri Bahar for the thermal as well as radiation environments.

In conclusion, these findings indicate that there should be a proper match between the growth phase of the crop and the temperature and sunlight profiles. This will ensure higher efficiency in resource use and high yield. Therefore, for highest productivity and efficiency in energy use, planting of Kufri Pushkar during the third week of October is advised, considering it to be the best combination in the region.

REFERENCES

1. Ahmadi SH, Jahan M, Kamkar B and Ansari H. Growth and phenology modelling of potato under different environmental conditions. Journal of Agronomy and Crop Science. 2019;205(3):299–311.
2. Asseng S, Ewert F, Rosenzweig C, Jones J W, Hatfield J L and Ruane A C. Uncertainty in simulating wheat yields under climate change. Nature Climate Change. 2015;3(9):827–32.
3. Chadha K L. Handbook of horticulture. New Delhi: ICAR Publication; 2009.
4. Darabi S, Ahmadi S H and Ansari H. Evaluating the thermal use efficiency of potato cultivars under different planting dates. Scientia Horticulturae. 2020; 261:109015.
5. Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India. Horticultural statistics at a glance. 2021.
6. Ezekiel R and Bhargava S C. Intercepted radiation, radiation use efficiency and dry matter production in potato as influenced by crop geometry and planting time. Indian Journal of Agricultural Sciences. 1997;67(5):186–90.

7. Haverkort A J. Ecology of potato cropping systems in relation to latitude and altitude. Agricultural Systems. 1990;32(3):251–72.
8. Hijmans R J, Spooner D M and Forbes GA. Climate change and the geographic distribution of potato cultivars and pathogens. American Journal of Potato Research. 2003;80(4):271–9.
9. International Potato Center (CIP). Potato facts and figures. 2018. Available from: https://cipotato.org
10. Kooman P L and Haverkort A J. Modelling development and growth of the potato crop influenced by temperature and daylength. European Journal of Agronomy. 1994;3(4):317–26.
11. Kumar R, Singh D and Barman D. Influence of planting time on growth and yield of potato under semi-arid conditions. Journal of Agrometeorology. 2019;21(1):62–7.
12. Monneveux P, Ramírez D A and Pino M T. Drought tolerance in potato. Journal of Crop Improvement. 2014;28(2):123–48.
13. Patel R M, Patel B K and Patel J C. Influence of planting dates on radiation interception and use efficiency in potato. Journal of the Indian Potato Association. 2000;27(1/2):43–6.
14. Rosenthal, W D and Gerik, T J. Radiation use efficiency among cotton cultivars. Agronomy Journal, 1991;83(4), 655-658.
15. Salack S, Muller B, Dieng D and Sarr B. Crop-climate ensemble-based scenarios to improve risk assessment and resilience in agriculture. Agricultural and Forest Meteorology. 2015; 203:11–23.
16. Samanta S, Behera B and Mandal B. Estimation of radiation use efficiency and productivity of potato crop using simulation modelling. Journal of Agrometeorology. 2020;22(3):309–15.
17. Sanwal S K, Singh R and Verma R. Effect of sowing date on growth, yield and quality of potato. Indian Journal of Agronomy. 2003;48(4):286–9.
18. Wang H, Li Y and Wang X. Responses of potato growth and yield to different thermal regimes under climate change scenarios. Agricultural and Forest Meteorology. 2015;214-215:280-9.