

**SIMULATING CROP WATER REQUIREMENT OF  
POTATO UNDER NATURAL FARMING ENVIRONMENT  
IN NORTH-WESTERN HIMALAYA**

**THESIS**

*By*

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**(A-2020-30-016)**

*Submitted to*



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*of*

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## **CERTIFICATE – I**

This is to certify that the thesis entitled “**Simulating crop water requirement of potato under Natural Farming environment in North-Western Himalaya**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy**, of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Sarthak Walia (Admission No. A-2020-30-016)** son of **Sh. Ajay Walia and Smt. Kusum Walia** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Palampur  
Dated:

**Dr. Ranbir Singh Rana**  
Major Advisor



## **CERTIFICATE- II**

This is to certify that the thesis entitled “**Simulating crop water requirement of potato under Natural Farming environment in North-Western Himalaya**” submitted by **Mr. Sarthak Walia** (Admission no. **A-2020-30-016**) son of **Sh. Ajay Walia** to the **CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur** in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy**, has been approved by the advisory committee after an oral examination of the student in collaboration with an external examiner.

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*Needless to mention, all errors and omissions are mine.*

Place : Palampur

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## LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	Rs	Rupees
2	%	Per cent
3	/	Per
4	cm	Centimetre
5	DAS	Days after sowing
6	et al.	Et alia (and others)
7	Fig.	Figure
8	g	Gram
9	Hr	Hour (s)
10	i.e.	Id est (that is)
11	Kg	Kilo gram
12	kg ha <sup>-1</sup>	Kilogram per hectare
13	mm	Millimetre
14	°C	Degree Celsius
15	q ha <sup>-1</sup>	Quintal per hectare
16	<i>viz.</i>	Namely
17	RMSE	Root Mean Square Error
18	w.r.t.	With respect to
19	CPE	Cumulative pan evaporation
20	IW	Irrigation water
21	mm	Millimetre
22	MCM	Million cubic metre

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**ABSTRACT**

A field experiment entitled “Simulating crop water requirement of potato under Natural Farming environment in North-Western Himalaya” was conducted during *Rabi* 2021-22 at Zero Budget Natural Farming research farm of Department of Organic Agriculture and Natural Farming, CSK HPKV, Palampur. The experiment comprising of four irrigation regimes viz; Limited irrigation (two), Limited irrigation (three), Penman Monteith at 60% AWC (four) and Penman Monteith at 50% AWC (five) with three dates of sowing (10<sup>th</sup> November, 10<sup>th</sup> December & 10<sup>th</sup> January) was laid out under Randomized Block Design with three replications. The soil of experimental site was silty clay loam in texture, acidic in reaction, medium in available nitrogen (268 kg ha<sup>-1</sup>), medium in available phosphorus (18.3 kg ha<sup>-1</sup>) and potassium (176.5 kg ha<sup>-1</sup>). The experimental site is located 32°6'N latitude and 76°3'E longitude. The experimental site received 384.9 mm rainfall during entire crop growth period. The results revealed that the plant growth parameters viz., plant height, no. of plants/m<sup>2</sup>, no. of leaves/plant, LAI recorded significantly higher values when crop was sown on 10<sup>th</sup> November under irrigation scheduling based on Penman Monteith at 50% AWC which included five irrigations. However, Penman Monteith at 60% AWC (four) and Penman Monteith at 50% AWC (five) did not vary statistically for yield parameters. Similarly, the yield parameters resulted in significantly higher yield under irrigation scheduling based on Penman Monteith at 60% AWC (four) (120.9 q ha<sup>-1</sup>) which was at par with Penman Monteith at 50% AWC (five) (123.4 q ha<sup>-1</sup>) compared to Limited irrigation (two) (100.2 q ha<sup>-1</sup>) and Limited irrigation (three) (109.6 q ha<sup>-1</sup>) treatments. The highest benefit cost ratio was observed for 10<sup>th</sup> November sown crop (1.70) and under irrigation scheduling based on Penman Monteith at 50% AWC (five) (1.66).

The validation of FAO-CROPWAT model was carried out and the root mean square error for estimated Evapotranspiration (ET) and Actual Evapotranspiration (AET) worked out from the field water balance method varied between 12.18 – 12.87% for different dates of sowing. The validated model was used to simulate elevated temperature regimes of 1°, 2°, 3°C rise in both maximum and minimum temperature, with 10%, 20% deficit rainfall and 10%, 20% rainfall surplus. With 1°, 2°, 3°C rise in temperature the increase in crop water requirement ranged between 3.7-9.84% for various sowing dates. The net irrigation water requirement increased ranging between 4.57-10.43% and 2.58-8.33% with 10% decrease and 10% increase in rainfall, respectively, whereas it ranged between 5.50-11.43% and 1.54-7.36% for rainfall deficit of 20% and surplus of 20%, respectively compared to normal weather conditions during the crop growth period for different sowing dates. The regression and principal component analysis indicated that there was 97.99%, 95.18% and 92.99% variation explained to dry matter with weather parameters for 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> date of sowing, respectively. The corresponding water footprints were lower in Penman Monteith at 60% AWC (four) compared to Penman Monteith at 50% AWC (five) which resulted in saving of 60 mm water for potato crop under Natural Farming environment in North-Western Himalayas.

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# 1. INTRODUCTION

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Potato crop is native to Peru and Bolivia in South America. It is a staple food in many European countries around the world and has proven its worth in feeding the nation in times of crisis. It is a good source of starch. A potato tuber contains 80 per cent water and 20 per cent dry matter consisting of 14 per cent starch, 2 per cent sugar, 2 per cent protein, 1 per cent minerals, 0.6 per cent fiber, 0.1 per cent fat, and vitamins B and C in adequate amount. Thus, potato provides more nutrition than cereals and vegetables. Potato is also having some medicinal uses such as it is anti-scorbutic. Persons with neurotic and liver dyspepsia digest it well. It is also employed as diuretic and galactagogue, nervous sedative and stimulant in gout. The leaves in the form of the extract are employed as an antispasmodic in chronic cough. Potato grind into a paste is applied as a plaster to burns caused by the fire with good results. The juice of the potato is a dark-colored liquid due to the presence of citric and succinic acids.

Potato is an important crop that is ideally suited to meet the growing food demand associated with population growth in the world's poor and developing countries, particularly in the tropics and South Asia, including India. It's ability to produce high-value food in a short period of time and adaptability to cropping systems make it a popular choice for growing in a variety of environments. In India, it is grown in an area of 2.2 million hectares having total production of 48.66 million tonnes (Anonymous, 2019). It is cultivated in almost all states under diverse agro-climate conditions. Uttar Pradesh, West Bengal, Bihar, Gujarat, Madhya Pradesh, Assam, Punjab, Haryana, Karnataka, Jharkhand and Himachal Pradesh are important potato growing states. In Himachal Pradesh, total production of potato was 1.96 Lakh MT in 2020-21 (Anonymous, 2022). The climatic conditions in many parts of the state offer excellent opportunity for producing both disease-free quality seed and table potato. In plains, the ideal time of planting corresponds to maximum and minimum temperatures of 30-32<sup>0</sup>C and 10- 20<sup>0</sup>C, respectively. In the hills, planting is done when the maximum temperature is about 20-22<sup>0</sup>C and minimum temperatures are about 12-15<sup>0</sup>C. In the Nilgiri hills, the temperatures remain mild throughout the year and three consecutive crops are grown during summer, autumn and winter (Patil et al. 2016).

In the era of modern agriculture, food production has increased substantially. However, the trends of agriculture on the other side also contribute to a large number of environmental issues including depleting water table and soil degradation. Natural farming philosophy is to work with nature to produce healthy food, to keep the land healthy and to keep ourselves healthy. Everything in nature is useful and serves a purpose in the web of life. It is also termed as “Do Nothing Farming”, because the farmer is considered only to be a facilitator - the real work is done by nature itself.

A self-sustaining system of agriculture like organic/natural farming may offer solution to many problems in Indian Agriculture. Natural farming envisages a comprehensive management approach to improve soil health and helps in water saving of 3.5 to 8.5% compared to inorganic farming (Shaikh and Gachande, 2016). It is a holistic method in which farmers are discouraged to buy market based inputs like chemical fertilizers, chemical pesticides etc. for growing plants within low budget and encourage to grow healthy soil with friendly earthworms and thereby grow healthy plants. It is a unique model that is based on 4 pillars viz. **Jeevamrutha** (mixture of fresh cow dung and aged cow urine from indigenous cow breed, jaggery, pulse flour, water and soil), **Bijamrita**: (concoction prepared from cow dung, cow urine, lime and soil), **Acchadana** (Residue Mulching) and **Whapasa**: (the condition where there are both air molecules and water molecules present).

Agriculture production is highly dependent on climatic and weather conditions, therefore, rising temperatures, precipitation, and CO<sub>2</sub> concentration have a direct impact on crop production. CO<sub>2</sub> levels are rising at a rate of 1.5 to 1.8 ppm per year. In India, rainfall is expected to fall by 0.7 % in 2050, 5.0 % in 2100 and temperature is projected to rise by 3-4 °C by the end of the century (Gupta et al. 2021). Water is one of the most key inputs for crop production. Both its shortage and excess affects crop yield and quality. Water scarcity has become the most prominent problem in Himachal Pradesh due to changing climate conditions during past three to four decades (Rana et al. 2014). Since, agriculture consumes the most water in India (81 percent), so efficient and smart water management has to be a top priority (Surendran et al. 2015).

Climate change is expected to change the spatial and temporal distribution of rainfall, as well as the rate of evaporation, resulting in changes in water availability and ground water recharge. As a result, future water requirements for different sectors

including agriculture needs to be assessed. In agricultural crop management evapotranspiration (ET) is regarded as the crop's total water requirement. ET-based irrigation scheduling also considers current weather conditions, which have been modified over the last few decades, as well as weather forecasts. Forecasts of weather parameters were found to be useful and profitable for effective decision making in agriculture, whereas the application of rainfall and temperature forecasts proved to be beneficial in saving irrigation in crops (Rana et al. 2005, Rana et al. 2012). As a result, employing the methodology for estimating ET is critical for modelling crop water requirements. Scientific crop water requirements are necessary for efficient irrigation scheduling, water resource planning, water balance, crop production potential assessment, and reservoir operation studies. We can do this by using different crop weather models for different crops. FAO CROPWAT is a model used for calculating crop water requirements and irrigation requirements based on the soil, climate and crop data.

Keeping this in view, present investigation entitled “**Simulating crop water requirement of potato under natural farming environment in north-western Himalaya**” has been formulated with the following objectives:

1. To work out the crop water requirement schedules based on different weather models.
2. To estimate futuristic crop water requirement under limited irrigations using validated FAO-CROPWAT Model under Natural farming conditions.

## **2. REVIEW OF LITERATURE**

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The pertinent literature available on the topic entitled “Simulating crop water requirement of potato under Natural Farming environment in North-western Himalaya” has been reviewed in this chapter under the following heads:

### **2.1 Effect of irrigation regimes on growth and yield attributes of potato**

### **2.2 Effect of sowing environment on growth and yield attributes of potato**

### **2.3 Effect of ET based irrigation scheduling on potato production**

### **2.4 Effect of agro meteorological indices on potato production**

### **2.5 Effect of natural farming practices on yield and irrigation management of potato**

#### **2.1 Effect of irrigation regimes on growth and yield attributes of potato**

Potato crop requires very precise amount of inputs to show the full potential of its yield and one such input is water. The review regarding various effects of irrigation water has been summarized here under:

Panda and Kashyap (2003) applied five irrigations based on maximum allowable depletion (MAD) in potato crop, the results revealed that fresh tuber yield of potato was significantly higher under high frequency irrigations than low frequency irrigations. The delayed irrigation significantly reduced the yield under 60 and 75 percent maximum allowable depletion (MAD) and fresh tuber yield decreased significantly as MAD increased from 45 to 75 per cent due to a decrease in water availability. Similarly, Onder et al. (2005) studied the effect of four different water stress levels viz. full irrigation ( $I_{100}$ ), 66% of full irrigation ( $I_{66}$ ), 33% of full irrigation ( $I_{33}$ ) and un-irrigated ( $I_0$ ) on potato yield in Hatay province located in the East Mediterranean Region of Turkey. They found that water stress had a significant impact on early potato yield and yield parameters, with a water deficit of more than 33% of the irrigation requirement producing unsatisfactory results. For both years, Treatment  $I_{33}$  provided the highest irrigation water use efficiency (IWUE). Whereas,

studies conducted by Pawar and Dingre (2008) in Rahuri, Maharashtra revealed that with the increase in irrigation level from 0.60 to 1.20 IW/CPE (in drip 0.5-1.10 wetted area) the tuber yield increased and at 1.4 IW/CPE ratio (in drip 1.30 wetted area) the yield decreased in all irrigation methods.

Badr et al. (2012) reported that the potato crop grown under full irrigation supply resulted in the highest tuber yield and there was significant reduction in total yield when applying less amount of water. Vishnoi et al. (2012) found out that the total water requirement for early and late sown potato crop came out to be 212.5 mm and 226.7 mm respectively. Kia (2013) used CROPWAT 8.0 to calculate the water requirements for potatoes in different agro-climatic zones of Iraqi Kurdistan. The highest CWR (Crop water requirement) for potato (704.1 mm) was at Makhmur and the lowest was at Chamchamal (491.2 mm); the highest irrigation requirement (IR) for potato was at Makhmur and the lowest at Chamchamal (401 mm). In another study by Cantore et al. (2014) in the Apulia region of Italy confirmed that reducing crop water requirement by half resulted in a satisfactory yield with tuber quality characteristics comparable to or even better than those obtained with full irrigation. Whereas, Ierna and Mauromicale (2018) reported that irrigation based on 100% of ET<sub>m</sub> is the most appropriate.

Mankotia and Sharma (2020) conducted an experiment at CSK HPKV in Palampur with ten treatments that included three drip irrigation levels, 0.4 PE, 0.6 PE, and 0.8 PE, as well as three fertigation levels, 50 percent RDF, 75 percent RDF, and 100 per cent. The researchers concluded that drip irrigation and fertigation with irrigation levels of 0.6 PE and 75% RDF produced better quality parameters. Furthermore, drip irrigation at 60% cumulative pan evaporation (0.6 PE) and 75% recommended NPK dose yielded the highest gross return (Rs. 285200 ha<sup>-1</sup>), net return (Rs. 153949 ha<sup>-1</sup>) and B:C ratio (2.17).

Gultekin and Ertek (2021) reported that as the water stress increased, the yield and quality decreased in potatoes, especially when water deficit was more than 30 %. Rangare et al. (2021) in their study found out that the water deficit condition imposed by the irrigation at 25 mm CPE reported for the maximum total tuber yield (21.89 t ha<sup>-1</sup> and 25.07 t ha<sup>-1</sup>) and marketable tuber yield (19.75 t ha<sup>-1</sup> and 23.74 t ha<sup>-1</sup>) for 75 DAP and 90 DAP, respectively.

## 2.2 Effect of sowing environment on growth and yield attributes of potato

The potato crop widely differ in it's developmental behaviour depending on the time of planting, agrometeorological conditions of the area and varietal characteristics. Sowing the crop at the appropriate time is the best way to adjust suitable weather conditions for the attainment of different phenological phases of the crop. The review on effect of different planting or sowing dates on potato crop is summarized here under:

Ravikant and Chadha (2005) concluded from their study that under N-W Himalaya, the average tuber weight of potato was higher in the autumn season crop (October) than in the spring season crop (April) due to sufficient vegetative growth and favourable climatic conditions for tuberization, viz., low temperature and short days. Sandhu et al. (2012) revealed that early planting of processing potato cultivars gave higher processing grade tuber yield with better chips' colour. Another study by Devi et al. (2013) during *rabi* season at Kalyani, Nadia revealed that early planting of potato resulted in maximum tuber weight per plant. At all the growth stages of crop, the dry matter production of tuber increased steadily but the rate of increase was slower at maturity. Sandhu et al. (2014) studied the effect of four different planting dates viz. 22<sup>nd</sup> October, 1<sup>st</sup> November, 11<sup>th</sup> November and 21<sup>st</sup> November, on plant growth attributes of potato. They reported that potato crop sown on 1<sup>st</sup> November provided the best yield.

Srivastava et al. (2016) confirmed that the highest number of tubers (9.6) and tuber weight per plant (243.8gm); marketable (14.4 t/ha) and total tuber yield (19.1 t/ha); Net return and B:C ratio (3.8) were recorded in the 1<sup>st</sup> March planting which were significantly superior over rest of planting dates. Ahmed et al. (2017) while studying the effect of planting dates on growth and yield performance of potato under three different dates of sowing viz., November 20, December 5 and December 29 revealed that maximum plant height, highest number of tubers/plant, highest leaf area, highest tuber weight/plant and maximum tuber yield were obtained with the crop sown on 5<sup>th</sup> December. Dash et al. (2018) conducted an experiment with five different dates of planting dates viz., 25<sup>th</sup> October, 5<sup>th</sup> November, 15<sup>th</sup> November, 25<sup>th</sup> November and 5<sup>th</sup> December. They found out that the potato crop planted on 15<sup>th</sup>

November had all the desired growth parameters with a maximum tuber yield of 24.019 t ha<sup>-1</sup>.

Sadawarti et al. (2019) conducted an experiment with five planting dates viz., 10<sup>th</sup> October, 17<sup>th</sup> October, 24<sup>th</sup> October, 31<sup>st</sup> October and 7<sup>th</sup> November and found that days to emergence and 50 % emergence were delayed in 10<sup>th</sup> and 17<sup>th</sup> October plantings, whereas the 7<sup>th</sup> November planting recorded higher growth and yield attributes such as number of stems, leaves, plant height and tuber yield. Similarly, studies conducted by Gogoi et al. (2020) with four different dates of planting, viz., 1<sup>st</sup> November, 11<sup>th</sup> November, 21<sup>st</sup> November and 1<sup>st</sup> December reported that the potato crop planted on 11<sup>th</sup> November recorded higher values for plant growth parameters viz., plant height, number of branches per plant, leaf area index, dry matter accumulation per plant, net assimilation rate, crop growth rate, relative growth rate and tuber yield. Whereas, Sharma (2021) reported that the plant growth and growth parameters viz., plant height, no. of plants/m<sup>2</sup>, no. of leaves/plant, LAI and tuber yield were recorded significantly higher when crop was sown on 10<sup>th</sup> December, compared to 30<sup>th</sup> December and 10<sup>th</sup> January, respectively.

### **2.3 Effect of evapotranspiration (ET) based irrigation scheduling on potato production**

The estimated impact of climate change on potato growth and production varies considerably across the globe. Considering the importance of water-related problems in the backdrop of climate change, the potential of the CROPWAT model in simulating water requirement can be harnessed.

Basahi (2007) reported that potato crop planted in January, February, March, April and May had higher evapotranspiration than crops planted in September, October, November and December. Chatterjee et al. (2012) used the field water balance method to calculate the ET values of potato crops, and the data was used to validate the CROPWAT model. Among the thirteen treatments, the field ET varied from 141.9 mm/season to 216.2 mm/season. The ET calculated by FWB method was compared with the ET calculated by CROPWAT 8.0 model and it was revealed that the CROPWAT model can be used safely for ET calculation as well as determination of irrigation requirement.

Vishnoi et al. (2012) used CROPWAT model to simulate the values of reference evapotranspiration (ET<sub>o</sub>) with Penman-Monteith equation and observed that the reference crop evapotranspiration (ET<sub>c</sub>) is highest (6.89 mm day<sup>-1</sup>) and lowest (1.46 mm day<sup>-1</sup>) in the months of May and January, respectively and the total water requirement of potato was more in case of late sown potato. Similarly, Babu et al. (2015) calibrated the CROPWAT model to estimate the crop water requirement, effective rainfall and irrigation. The crop water requirement for the groundnut *kharif* and *rabi* crops in Anantapur region was estimated to be 591.3 mm and 443.3 mm, respectively and for vegetables it was 594.1 mm. Sood et al. (2015) investigated that the decision support system (DSS) models like DSAT, Info crop etc. provide the crop simulation scenarios and help the policy makers to finalise the farm practices like fertilizer dose, irrigation scheduling and time of sowing, the scenario can be simulated and the best variety can be opted for better yields

Banerjee et al. (2016) validated the CROPWAT 8.0 model for the Lower Gangetic Plains of India to estimate the evapotranspiration from potato fields and for calculating the IWR. It was revealed that, if there is an increase of temperature by 2°C over normal prevailing temperature, the simulated ET will be enhanced by 0.06 mm per day over the present level with 6.0 mm extra IWR for potato. If temperature is 3 °C above the normal, the IWR will be enhanced by 16.6 mm.

Mattar et al. (2016) investigated five different reference evapotranspiration models (three radiation-based models, one temperature based model and one combined model) under hyper-arid environmental conditions and confirmed that the FAO 56 PM model performed best in estimating ET<sub>c</sub>, with only a 2% underestimation. The temperature-based model (Hargreaves-Samani) underestimated ET<sub>c</sub> by 20%, while the radiation-based models (Priestley-Taylor and Makkink) underestimated ET<sub>c</sub> by 35%. Dar et al. (2017) also reported that Penman-Monteith is the most accurate model for predicting ET. Similarly, Poddar et al. (2021) conducted a study in Hamirpur, Himachal Pradesh to find the crop evapotranspiration (ET<sub>c</sub>) and crop coefficient (K<sub>c</sub>) values for different growth stages (initial, mid-season and late-season) of potato crop. The ET<sub>o</sub> values were calculated by using Penman-Monteith

method. The maximum, minimum and mean  $ET_0$  values were  $7.59 \text{ mm day}^{-1}$ ,  $0.55 \text{ mm day}^{-1}$  and  $3.94 \text{ mm day}^{-1}$  respectively. FAO (Allen et al. 1998) proposed  $K_c$  ini,  $K_c$  mid and  $K_c$  end as 0.15, 1.1 and 0.65 for potato. The modified values of  $K_c$  ini,  $K_c$  mid and  $K_c$  end were 0.31, 1.41 and 0.48 for potato for the particular sub-humid sub-tropical region.

Memon and Jamsa (2018) used FAO- CROPWAT 8.0 software to determined the Crop Water Requirement (CWR) and irrigation scheduling of soybean and tomato crop at Godhra, Gujarat, India and confirmed that the use of modern scientific tools like CROPWAT can assess the water requirement of crops with large accuracy and suggest the crop pattern and crop rotation which can be readily acceptable to farmers. In another study conducted by Sanjeev (2018) on five reference evapotranspiration models i.e. no irrigation or rainfed, Thornthwaite method, Hargreaves method, Temperature method and Penman-Monteith method at Palampur, Himachal Pradesh. The results revealed that the irrigation scheduling based on FAO Penman Monteith method was the most suitable practice for saving one irrigation without affecting the growth and yield attributes statistically. The lowest water footprints to the tune of 300 litres of water per kg of potato were obtained in Penman Monteith ET estimation method. Kumar et al. (2020) evaluated thirteen different  $ET_0$  methods for estimating  $ET_c$  using the FAO-56 crop coefficient approach. Based on the findings of the study, it was concluded that the Penman-Monteith (PEN-M), FAO-24 radiation (RAD) (radiation-based), Hargreaves-Samani (HAR) (temperature-based) and Snyder (SD) (pan-evaporation based) methods can be used as suitable alternatives for estimating the field  $ET_c$  in the absence of the lysimetric measurements.

Kadam et al. (2021) used the Penman-Monteith method to calculate reference evapotranspiration ( $ET_0$ ); and crop coefficients were computed using the standard FAO-56 methodology. It was observed that the total reference evapotranspiration ( $ET_0$ ) and crop evapotranspiration ( $ET_c$ ) were 226 and 240 mm in 2015–2016 and 248 and 250 mm in 2016–2017, respectively. The average estimated  $K_c$  values for semi-arid region's during the vegetative, tuber development and maturity stages were found out to be 0.55, 1.11, and 1.01, respectively. The calculated values were slightly

lower than those suggested by FAO-56 for the vegetative and tuber development stages and higher for the maturity stage of potato. Similarly, Sharma et al. (2022) conducted a study to determine the crop water requirement for Upper Ganga Canal command area using CROPWAT 8.0 model. It was observed that the high degree of accuracy in the estimation of crop water requirements through CROPWAT is helpful in improving the overall efficiency of agricultural practices in the area.

#### **2.4 Effect of agro meteorological indices and potato production**

Worthington and Hutchinson (2005) evaluated potato crop with six planting dates and observed that GDD increased with advance sowing. Whereas, Apotikar and Solanke (2011) found out that the highest GDD was found in the potato crop with five irrigations and mulching treatment. Nath et al. (2014) studied the impact of thermal environment on the growth and productivity of potato sown on five different dates from 15th November onwards having an interval of seven days each and observed that the GDD gradually decreased with the delay in planting.

Barman et al. (2019) carried out a field experiment during at Jorhat, Assam to study crop-weather relationships of potato grown under three different dates of sowing viz., 16<sup>th</sup> November, 1<sup>st</sup> December and 16<sup>th</sup> December. It was revealed that with increasing Accumulated growing degree-days (AGDD) there was a significant increase in the plant height, LAI and total biomass in case of all different growth stage. Sharma (2021) investigated the impact of various agro-meteorological indices on potato growth and yield. It was found that growing degree days showed an increasing trend with the advanced sowing dates and a decreasing trend with the increase in number of irrigations. The same trend was observed in case of helio-thermal units, photo-thermal units, pheno-thermal index and heat use efficiency.

#### **2.5 Effect of Natural Farming practices on yield and irrigation management of potato**

Natural farming is a chemical-free approach of agriculture drawing its' origin from traditional Indian farm practices. It was originally promoted by prominent agriculturist and Padma Shri recipient Shri Subhash Palekar, who developed it in the mid-1990s as an alternative to the Green Revolution's methods. It is based on 4 agro-ecological pillars viz. Jeevamrutha (mixture of fresh cow dung and aged cow urine

from indigenous cow breed, jaggery, pulse flour, water and soil, Bijamrita: (concoction prepared from cow dung, cow urine, lime and soil), Acchadana (Residue Mulching) and Whapasa: (the condition where there are both air molecules and water molecules present).

Mukherjee et al. (2010) assessed the effect of mulching on water use efficiency and evaporation in tomato crop irrigated with cumulative pan evaporation 50mm, 25mm and rainfed. They discovered that actual evaporation rate was 1.82 mm/day that declined by 31 per cent with the application of mulch. Ravikumar et al. (2011) reported that application of *jeevamrit* in conjunction with biodigester resulted in higher yield in groundnut. Similarly, Boraiah (2013) observed that the application of *jeevamrit* resulted in 7.98 to 26.20 per cent increase in fruit yield of chilli when compared to no *jeevamrit* application. Acharya and Kapur (2014) reported that the potato crop sown with pine needle mulch @ 10 tonnes/ha saved one irrigation and gave about 50% higher yield of autumn and 22% higher tuber yield of spring crop.

Patil et al. (2014) observed in a field experiment conducted at MPKV, Rahuri that with the application of organic manures such as FYM @ 2.5 t/ha + vermicompost @ 1 t/ha + 2 times *jeevamrit* @500 L/ha, there was a significant increase in pigeon pea growth attributes such as plant height, number of branches per plant, number of compound leaves, seed and stalk yield. Kumbar et al. (2015) revealed that combined application of FYM, *jeevamrit* and *panchagavya* resulted in higher pod yield (148.3 and 163.2 q/ha), pod weight (86.69 and 97.12 g/plant) and number of pods per plant (16.70 and 18.76) of frenchbean.

Singh et al. (2015) stated that the rice residue mulch @ 6t/ha reduced the soil water evaporation, thereby helped in maintaining 0.8 to 1.7% more moisture than no mulch conditions. Similarly, Bhagat et al. (2016) studied the impact of straw mulch on plant growth parameters of potato. They reported that maximum tuber yield (366.8 q/ha) were observed with the treatment having rice straw mulch @ 6 tonnes/ha. Shaikh and Gachande (2016) studied the effect of various liquid organic inputs and inorganic inputs on soil physico-chemical properties in Maharashtra and revealed that in organic inputs applied field, there was significant increase in water holding capacity (3.3 % to 8.5 %) over inorganic inputs applied.

Pathak (2017) studied the integrated nutrient management practices in garlic at Solan and found out that seed treatment with *beejamrit* (overnight) + application of *jeevamrit* (fortnight application) + recommended FYM (250q/ha) as basal dose at the time of field preparation resulted in more profitable crop. Kumari et al. (2019) investigated the effect of organic nutrient sources on nutrient uptake and different soil properties in onion and concluded that the application of vermicompost @ 8 t ha<sup>-1</sup> + *jeevamrit* (drenching, 5%) optimized the nutrient requirement of onion crop for better yield and quality. Singh (2019) conducted an experiment to study the effect of biofertilizers and organic amendments on growth and yield of garlic. The results concluded that the application of 90 per cent recommended dose of nitrogen + *panchagavya* (5%) + *jeevamrit* (5%) gave significantly higher bulb yield compared to other combinations.

Sekhon et al. (2020) observed that mulching resulted in significantly higher marketable tuber yield than non-mulched conditions in potato crop. Similar trends were observed in case of yield attributing parameters viz. plant height, number of haulms per plant and number of marketable tubers per plant. The water use efficiency was also higher under mulched plots.

Singh (2020) conducted a field experiment to investigate the effect of integrated nutrient management practices in garlic at Solan and reported that the combined application of 100 per cent recommended dose of NPK + 50 kg Sulphur/ha + 5 per cent *jeevamrit* @ 1 L/ m<sup>2</sup> gave significantly higher values of yield and yield contributing traits. Similarly, Sharma (2021) studied the effect of Natural Farming practices on growth, yield and quality of garlic at Palampur, Himachal Pradesh and found out that the applications of *jeevamrit* after 14 days recorded significantly higher bulb yield (121.59 q ha<sup>-1</sup>) compared to absolute control (68.25 q ha<sup>-1</sup>). He further stated that the natural farming practices were not only economically beneficial but also helped in rejuvenation of the soil.

Kumar et al. (2022) conducted field experiments during *kharif* 2019 and 2020 at Palampur to evaluate the comparative efficacy of different components of natural farming on crop production and economics of black gram. They concluded that application of *ghanjeevamrit* + *jeevamrit* + mulching (T<sub>7</sub>) significantly increased the seed yield of black gram over T<sub>8</sub> (absolute control) by 61.4 and 233.1 per cent during 2019 and 2020, respectively.

### 3. MATERIALS AND METHODS

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The present investigation entitled, “Simulating crop water requirement of potato under natural farming environment in north-western Himalaya” was carried out during *rabi* 2021-22 at Zero budget natural farm of Department of Organic Agriculture and Natural Farming, CSK HPKV, Palampur (Himachal Pradesh). The details of the materials used and the methods adopted during the course of the investigation are described in this chapter:

#### 3.1 Experimental site

The experimental farm is situated at 32°07' N latitude, 76°23' E longitude and at an altitude of 1290.8 m above mean sea level in North Western Himalayas. The farm is exclusively under Natural Farming environment for the last 4 years.

#### 3.2 Weather conditions

Agro climatically, the experimental site falls under sub-temperate and sub-humid zone, characterized by high rainfall with mild summers (19.0-31.0°C) and severe winters (3.5 -13.4°C). The average annual rainfall is 2280 mm out of which 80 per cent is received during June to September. The hottest months are May and June and the coldest being December and January. Winter rainfall is received mainly from December to February.

Mean weekly weather parameters viz; maximum and minimum temperature, relative humidity, evaporation, bright sunshine hours, and rainfall during the crop season (November, 2021 to May, 2022) recorded at meteorological observatory of the Department of Agronomy have been given in Appendix-I and illustrated graphically in Fig 3.1. The data showed that the weekly minimum and maximum temperature ranged from 2.1 to 18.3°C and 10.9 to 31.3 °C, respectively. The total rainfall was 384.9 mm and mean relative humidity ranged between 40.4 to 90.3 per cent during the crop growth period. The cumulative pan evaporation during crop season was 641.2 mm. The monthly ET ranged from 58.2-126.6.5 mm. The bright sunshine hours ranged between 4.5 to 9.1 hour.

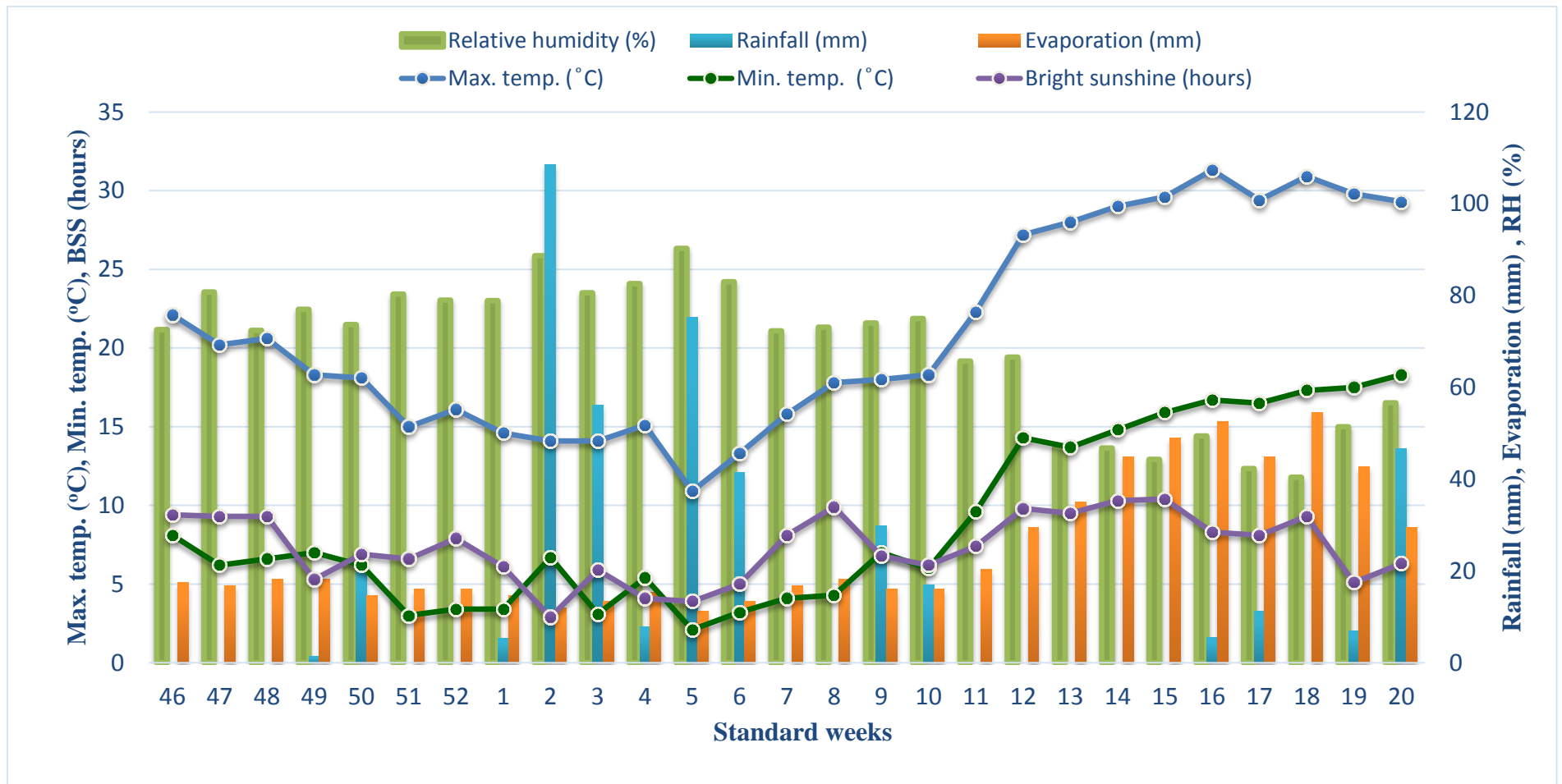


Fig. 3.1 Mean weekly weather data from November 2021 to May 2022 (Met week No. 46 to 20)

### 3.3.1 Soil analysis

Before sowing of the crop the composite soil samples were collected from 0-15 cm depth from the experimental field. The soil samples were then air dried, passed through 2 mm sieve and finally analyzed for various physico-chemical properties as per standard methods. The results of the analysis have been presented in Table 3.1

**Table 3.1 Initial physico-chemical properties of experimental site (0-15 cm)**

Soil characteristic	Content	Method
<b>A. Mechanical analysis</b>		
Sand (%)	16.4	
Silt (%)	44.7	International pipette method (Piper 1966)
Clay (%)	37.8	
Texture	Silty clay loam	
<b>B. Chemical analysis</b>		
pH (1:2.5 soil water suspension)	5.7	Glass electrode pH meter method (Jackson 1967)
Organic carbon (%)	0.72	Rapid titration method (Walkley and Black 1934)
Available Nitrogen (kg ha <sup>-1</sup> )	268	Alkaline permanganate method (Subbiah and Asija 1956)
Available Phosphorus (kg ha <sup>-1</sup> )	18.3	0.5N NaHCO <sub>3</sub> extractant (Olsen et al. 1954)
Available Potassium (kg ha <sup>-1</sup> )	176.5	Ammonium acetate extraction method (AOAC, 1970)

### 3.3.2 Cropping History

The experimental field was under the cultivation of adzukibean in *kharif* and wheat during *rabi* for the last seasons.

Year and season	Crop
<i>Rabi</i> , 2020-21	Wheat
<i>Kharif</i> , 2021	Adzukibean

### 3.4 Experimental details

The field experiments were conducted in randomized block design (RBD) during the *rabi* season of 2021-22 with the combination of three dates of sowing and four irrigation regimes with three replications.

#### 3.4.1 Treatment details

The treatments consisted of various irrigation regimes based on ET and different dates of sowing. The treatment details are as below:

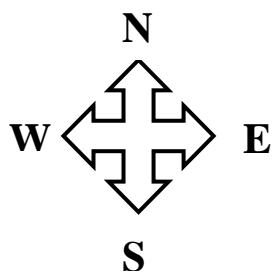
Date of sowing	Variety	
		Treatment combinations = 12
D <sub>1</sub> = 10 <sup>th</sup> November, 2021	Kufri Jyoti	Design RBD
		Replications – Three
		Total no. of plots – 36
D <sub>2</sub> = 10 <sup>th</sup> December, 2021		Gross plot size=4*3m <sup>2</sup> =12m <sup>2</sup>
		Net plot size = 3.50*2.50m <sup>2</sup> =8.75m <sup>2</sup>
		Where,
D <sub>3</sub> = 10 <sup>th</sup> January, 2022		I <sub>1</sub> = Limited irrigations (two irrigations)
		I <sub>2</sub> = Limited irrigations (three irrigations)
		I <sub>3</sub> = Irrigation (four) scheduling based on ET Penman monteith at 60% AWC
		I <sub>4</sub> = Irrigation (five) scheduling based on ET Penman monteith at 50% AWC

### **3.4.2 Sowing**

The potato tubers of variety Kufri Jyoti were cut into pieces of 30-50 g and treated with *Beejamrit*. The planting was done in well prepared soil on 10<sup>th</sup> November, 10<sup>th</sup> December, 2021 and 10<sup>th</sup> January, 2022. Planting was done in well prepared soil at a spacing of 50 cm row to row and 20 cm plant to plant in ridges made manually as per the treatment. The pre-sowing irrigation was applied 7days before the sowing

### **3.4.3 Layout**

The experiment was carried out in randomized block design consisting of twelve treatments three replications. The layout of the field showing randomization of the treatments has been shown in Fig 3.2.



	1	2	3	4	5	6	7	8	9	10	11	12
Rep I	D <sub>1</sub> I <sub>2</sub>	D <sub>2</sub> I <sub>3</sub>	D <sub>3</sub> I <sub>1</sub>	D <sub>1</sub> I <sub>4</sub>	D <sub>2</sub> I <sub>1</sub>	D <sub>3</sub> I <sub>2</sub>	D <sub>1</sub> I <sub>3</sub>	D <sub>2</sub> I <sub>2</sub>	D <sub>3</sub> I <sub>4</sub>	D <sub>1</sub> I <sub>1</sub>	D <sub>2</sub> I <sub>4</sub>	D <sub>3</sub> I <sub>3</sub>
Rep II	D <sub>2</sub> I <sub>3</sub>	D <sub>3</sub> I <sub>2</sub>	D <sub>1</sub> I <sub>1</sub>	D <sub>2</sub> I <sub>4</sub>	D <sub>1</sub> I <sub>2</sub>	D <sub>2</sub> I <sub>1</sub>	D <sub>3</sub> I <sub>4</sub>	D <sub>1</sub> I <sub>3</sub>	D <sub>3</sub> I <sub>3</sub>	D <sub>1</sub> I <sub>4</sub>	D <sub>2</sub> I <sub>2</sub>	D <sub>3</sub> I <sub>1</sub>
Rep III	D <sub>2</sub> I <sub>2</sub>	D <sub>3</sub> I <sub>3</sub>	D <sub>1</sub> I <sub>1</sub>	D <sub>2</sub> I <sub>4</sub>	D <sub>1</sub> I <sub>4</sub>	D <sub>2</sub> I <sub>1</sub>	D <sub>3</sub> I <sub>4</sub>	D <sub>1</sub> I <sub>3</sub>	D <sub>3</sub> I <sub>2</sub>	D <sub>1</sub> I <sub>2</sub>	D <sub>2</sub> I <sub>3</sub>	D <sub>3</sub> I <sub>2</sub>

Fig 3.2 Layout of the field experiment

### 3.5 Cultural operations

The details of cultural operations and crop management practices adopted during the crop growth period have been given below (Table 3.2).

**Table 3.2 Details of field operations during *rabi* season of 2021-22**

S.No.	Field operations	1 <sup>st</sup> Date of sowing	2 <sup>nd</sup> Date of sowing	3 <sup>rd</sup> Date of sowing
1.	Field preparation	6.12.2021	6.12.2021	6.12.2021
2.	Layout	9.11.2021	9.11.2021	9.11.2021
3.	Sowing	10.11.2021	10.12.2021	10.01.2022
4.	Basal application of <i>Ghanjeevamrit</i>	10.11.2021	10.12.2021	10.01.2022
5.	<i>Jeevamrit</i> spray (10%)	14 days interval	14 days interval	14 days interval
7.	Earthing up	15.01.2022 19.02.2022	16.02.2022 22.03.2022	25.02.2021 22.03.2021
8.	Hand weeding	28.01.2021	20.01.2021	28.01.2021
9.	Harvesting	28.04.2021	04.05.2021	09.05.2021

#### 3.5.1 Field preparation

The experimental field was irrigated prior to sowing and then ploughed once it achieved the optimum moisture level. One more ploughing was done with the help of power tiller (small) and then layout of the field was done. The furrows were made at a spacing of 50cm and the potato tubers containing 2-3 eyes were planted.

### 3.5.2 Estimation of Evapotranspiration using FAO-CROPWAT model

The FAO-CROPWAT is a water balance-based crop weather model that uses climatic and crop data to calculate crop water requirements and irrigation water requirements. In addition, the programme allows for the development of irrigation schedules for different management conditions as well as the calculation of scheme water supply for various cropping patterns. It makes use of the Penman-Monteith method for calculation of evapotranspiration. The Penman-Monteith Equation is given by the following equation (FAO, 1998a):

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

Where:

$ET_o$  = Reference evapotranspiration (mm/day)

$R_n$  = Net radiation at the crop surface ( $MJ/m^2$  per day)

$G$  = Soil heat flux density ( $MJ/m^2$  per day)

$T$  = Mean daily air temperature at 2 m height ( $^{\circ}C$ )

$u_2$  = Wind speed at 2 m height (m/sec)

$e_s$  = Saturation vapour pressure (kPa)

$e_a$  = Actual vapour pressure (kPa)

$e_s - e_a$  = Saturation vapour pressure deficit (kPa)

$\Delta$  = Slope of saturation vapour pressure curve at temperature  $T$  ( $kPa/^{\circ}C$ )

$\gamma$  = Psychrometric constant ( $kPa/^{\circ}C$ )

#### Various inputs used in CROPWAT are:

The different inputs that were used in the CROPWAT model were daily maximum and minimum temperature, relative humidity, wind speed and sunshine hours. The rainfall data on daily base was used. The plant data comprised of crop coefficient, number of days taken to different developmental stages, depletion of moisture at different stages, yield response and plant height. The soil data used as input was soil type, total available soil moisture, maximum rooting depth, initial soil

moisture depletion and initial available soil moisture. These inputs were used to calculate the crop water requirement and irrigation scheduling for the crop.

### **Crop coefficient and irrigation scheduling.**

The values for potato crop coefficient were obtained from FAO for sub-temperate conditions and then they were modelled for the local region using the crop phenology. The Kc values obtained were then used for calculating total crop water requirement of the potato. The real time rainfall was also added up to prepare the irrigation schedule. The soil was saturated with 100 percent 60 mm irrigation water, and further depletion was calculated using the Penman-Monteith ET based method. The irrigation was given when the crop evapotranspiration (ET) loss was 53% i.e. out of 60mm irrigation applied it reduce to 32mm in case of treatment I<sub>1</sub> and I<sub>2</sub>. For treatment I<sub>3</sub> the irrigation was given at 40% crop evapotranspiration (ET) loss i.e. out of 60mm irrigation applied it reduced to 24mm and in case of treatment I<sub>4</sub> irrigation was given when the crop evapotranspiration (ET) loss was 50% i.e. 30mm out of 60mm. Different irrigation treatments (two, three, four, five irrigations) were used to see the changes in crop yield. Below are the crop coefficient values used for the initial stage, Kc Mid stage, and Kc End stage:

Name of crop	Initial 27days	Kc Mid 45days	Kc End 30 days
Potato	0.50	1.15	0.75

Where,

*Initial stage:* It starts from planting date to approximately 10% ground cover.

*Developmental stage:* It runs from 10% ground cover to effective full cover (which is generally up to initial flowering)

*Mid Stage:* It is from effective full cover to start of maturity (when ageing begins, senescence).

*Late season stage:* From start of maturity to the harvest.

### **Water footprints and total crop water requirement.**

The water footprints is known as the total water used per kg of the yield of potato. It was calculated using CROPWAT model. The total crop ET was taken as total water requirement. The pan evaporation data was used for IW/CPE ratio method for working out total water requirement but was not used as a treatment. IW/CPE ratio method has been very extensively used by many workers.

## **3.6 Crop studies**

### **3.6.1 Phenological studies**

#### **i. Days to complete emergence stage**

A sampling area of one-meter length was earmarked at two sites in each net plot of the experiment. Daily counts of the earmarked potato plants were made until the constant value was reached. The number of days taken to complete emergence were counted from the date of sowing.

#### **ii. Days to vegetative growth stage**

The total number of days taken for the vegetative growth was calculated from the date of planting of the potato crop to the 10% of the ground cover.

#### **iii. Days to tuber initiation stage**

The days to tuber initiation were recorded from the earmarked one-meter row length in each net plot from the date of emergence of seedling. The tuber initiation stage in potato is accessed when tip of stolon start to swell and became rounded. The number of days taken to tuber initiation was counted from the date of emergence.

#### **iv. Days to tuber bulking stage**

The days to tuber bulking were taken from the date of planting of the potato crop. In this stage the tuber cells expand with the accumulation of water, nutrients and carbohydrates.

**v. Days to harvest stage**

The days to harvest were recorded from sowing date to 95 per cent maturity. In potato it is assessed when the foliage of the crop has dried naturally and the tuber skin has set.

**3.6.2 Biomass studies**

For this the dry matter accumulation was recorded at 10 days interval after emergence till maturity. The plant samples were taken from the second row that is near the border row at both sides of the plot. From each plot two plants were taken. The plant samples were sun dried followed by hot air oven drying at 70°C till the constant weight was achieved and then converted to g m<sup>-2</sup> and presented in kg per hectare.

**3.6.3 Growth and yield attributes****i. Plant height**

The height of five randomly selected plants were taken from net plot area at monthly interval after planting till harvest. Meter rod was used for measuring the height. The height was taken from the base of plant to the highest leaf tip in centimetres. The average height of five plants was calculated and expressed as plant height per plant at each time interval.

**ii. Root length (rooting depth)**

The root length of five randomly selected plants were taken from net plot area at 90 days after planting and at harvest. Meter rod was used for measuring the length. The average length of five plant roots was calculated.

**iii. Number of plants per m<sup>2</sup>**

The total number of plants present in 1m<sup>2</sup> area was counted at vegetative maturity of the crop and was recorded as number of plants m<sup>-2</sup>. The area of 1m<sup>2</sup> was marked in each plot using four sticks and then the plants were counted in the given area.

**iv. Number of leaves per plant**

The photosynthetically active (75% green) leaves of five randomly selected plants from each plot were counted at 30 days interval from date of planting. The average was taken to find number of leaves.

**v. Leaf area index**

The leaf area per plant of five randomly selected plants from each plot was calculated using the length and breadth of the different leaves and then the leaf area index was calculated.

**vi. Number of shoots per plant**

The total number of haulms were counted of five randomly selected plants from each net plot. Then the average number of haulms per plant was worked out.

**vii. Number of tubers per plant**

The number of tubers per plant were recorded of five randomly selected plants from each plot and then the average number of tubers per plant was computed.

**viii. Average tuber weight**

The average weight of tubers was calculated from randomly selecting ten tubers of different grades in each plot. The weight of these selected tubers was taken and average was calculated.

**ix. Grading**

The produce from each net plot was graded into different grades on the basis of average weight of tuber as explained below:

Grade A tuber weight > 75g

Grade B tuber weight 50-75g

Grade C tuber weight <50g

Weight of total tubers of different grades was taken and data was converted into quintals per hectare.

**x. Tuber yield**

The harvesting of crop was done with the help of spade by digging the plants from net sown area and the potato tubers were separated from the plants. The tuber yield so obtained from each plot was recorded and converted in quintals per hectare (q/ha).

### 3.7 Agro meteorological indices

#### 3.7.1 Growing degree days (GDD)

The GDD were computed using Tijare et al. (2017) method as given below:

$$\text{GDD} = (T_{\max} + T_{\min})/2 - T_t$$

Where,

$T_{\max}$  = Maximum temperature (°C) of the day

$T_{\min}$  = Minimum temperature (°C) of the day

$T_t$  = Threshold temperature (4.5 °C, Hundal et al. 1997)

GDD is expressed as °C days.

#### 3.7.2 Helio thermal units

Helio thermal units (HTU) were calculated by using the method given by Chakarvarty and Sastry (1985). The actual bright sunshine hours were used in place of total day length in PTU to arrive at heat summations. Hence, the product of growing degree days and corresponding actual bright sunshine hours has been termed as helio thermal units and accumulated for the crop growth period.

$$\text{HTU} = \text{GDD} * \text{actual sunshine hours}$$

HTU is expressed as °C day hours.

#### 3.7.3 Photo thermal units

The product of the growing degree days and the day length in hours over a given period is expressed as photo thermal units (Tijare et al. (2017)).

$$\text{PTU} = \text{GDD} * \text{day length}$$

PTU is expressed as °C day hours.

### 3.7.4 Pheno-thermal index

It was computed by the heat units accumulated per day between two phenological stages and is expressed as degree-days per growth day (Chakravarty and Sastry (1985).

$$PTI = \frac{\text{Degree days consumed between two phenological stages}}{\text{Number of days between two phenological stages}}$$

PTI is expressed as °C day/days.

### 3.7.5 Heat use efficiency (HUE)

Heat use efficiency is defined as the heat utilized to produce one unit of plant biomass. The heat use efficiency is calculated by taking the ratio of dry matter and the GDD.

$$HUE = \frac{\text{Dry matter}}{\Sigma \text{GDD}}$$

HUE is expressed as kg/ha/°C days.

## 3.8 Correlation and regression studies

Correlation and regression studies were carried out between biomass and weather parameters after doing the statistical analysis of the data as per Gomez and Gomez (1984).

## 3.9 Soil studies

### 3.9.1 Soil water studies

Soil sample from each plot were taken with the help of auger from 0-15 cm and 15-30 cm at 10 days interval. The soil samples were also taken before and after irrigations and soil moisture was observed. The fresh soil samples were oven dried at 105°C till constant weight was obtained. The soil moisture percentage was then calculated on oven dry weight basis with the help of given formula:

$$\text{Soil moisture}(M_p) = \frac{\text{Fresh weight}(F_w) - \text{Dry weight}(D_w)}{\text{Dry weight}(D_w) - \text{Empty box weight}} \times 100$$

where;

$M_p$  = Moisture percentage on oven dry weight basis

$F_w$  = Fresh weight of soil sample

$D_w$  = Dry weight of soil sample

### **3.9.2 Soil analysis**

The initial status of the soil was determined for available N, P, K, texture, pH and organic carbon content.

#### **a. Available Nitrogen**

The available nitrogen was determined by alkaline permanganate method (Subbhiah and Asija 1956).

#### **b. Available Phosphorus**

The available phosphorus was determined by Olsen's method (Olsen et al. 1954).

#### **c. Available Potassium**

The available potassium was determined by Ammonium acetate extraction method (Black 1965).

#### **d. Soil texture**

The texture of the soil was determined by international pipette method (Piper 1966).

#### **e. Soil pH**

The soil pH was determined by Glass electrode pH meter method (Jackson 1967).

#### **f. Organic carbon**

The organic carbon was determined by Rapid titration method (Walkley and Black 1934)

### **3.10 Economic studies**

The economics of each treatment was worked out in order to find the most profitable treatment on the basis of prevalent market prices of the inputs and output.

#### **3.10.1 Cost of cultivation**

The cost of cultivation was computed by adding all the costs which were involved in each operation or input.

### 3.10.2 Gross returns

Based on the prevailing market price the yield of the crop was converted into gross returns in rupees to obtain treatment-wise gross returns.

### 3.10.3 Net returns

The net returns for each treatment was obtained by subtracting the cost of cultivation from the gross returns.

### 3.10.4 Benefit cost ratio

The return per rupee invested was calculated as given below:

$$\text{Benefit cost ratio (B: C)} = \frac{\text{Net return (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

### 3.11 FAO CROPWAT model

The FAO CROPWAT model was calibrated and validated for the potato crop under limited irrigation scenarios with AET data obtained from soil water balance method. It was used to simulate the crop water requirements for the potato crop in the area under study.

## **4. RESULTS AND DISCUSSION**

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The experimental findings ensued from the present investigation entitled “Simulating crop water requirement of potato under natural farming environment in north-western Himalaya” have been described in this chapter through tables and figures. An attempt has been made to establish the cause and effect relationships of experimental research findings by providing possible scientific explanations and supportive evidences based on the available literature. The results have been discussed and presented under the following headings:

### **4.1 Phenological studies**

4.1.1 Days to complete emergence stage

4.1.2 Days to vegetative growth stage

4.1.3 Days to tuber initiation stage

4.1.4 Days to tuber bulking stage

4.1.5 Days to maturity stage

### **4.2 Biomass studies**

### **4.3 Growth studies**

4.3.1 Plant height

4.3.2 Root length (Rooting depth)

4.3.3 Number of plants per sq. m.

4.3.4 Number of leaves per plant

4.3.5 Leaf area index

### **4.4 Yield attributes**

4.4.1 Number of shoots per plant

4.4.2 Number of tubers per plant

4.4.3 Average tuber weight

4.4.4 Grading

4.4.5 Tuber yield

#### **4.5 Validation of FAO – CROPWAT model**

#### **4.6 Estimation of evapotranspiration**

4.6.1 Estimated Reference Evapotranspiration ( $ET_o$ ).

4.6.2 Estimated Crop Evapotranspiration ( $ET_c$ )

4.6.3 Irrigation scheduling by different methods

4.6.4 Soil water content

4.6.5 Total rainfall and effective rainfall

4.6.6 Water footprints

#### **4.7 Agro meteorological indices**

4.7.1 Growing degree days (GDD)

4.7.2 Helio thermal units (HTU)

4.7.3 Photo thermal units (PTU)

4.7.4 Pheno thermal index (PTI)

4.7.5 Heat use efficiency (HUE)

#### **4.8 Correlation and Regression studies**

4.8.1 Correlation studies

4.8.2 Regression and Principal component analysis

#### **4.9 Impact of rise in temperature and changing rainfall scenarios on $ET_o$ and $ET_c$**

#### **4.10 Impact of rise in temperature and changing rainfall scenarios on present and futuristic irrigation water requirement of potato crop**

#### **4.11 Economic studies:**

4.11.1 Cost of production

4.11.2 Gross and net returns

4.11.3 B:C ratio

## **4.1 Phenological studies**

The data on number of days taken to complete emergence stage, days taken for the vegetative growth stage, days taken to tuber initiation stage, days taken to tuber bulking stage and days taken for harvest stage under various treatments has been presented in Table 4.1.

### **4.1.1 Days to complete emergence stage**

A scrutiny of the data presented in Table 4.1 revealed that the days taken for the complete emergence were maximum for 10<sup>th</sup> November sowing followed by 10<sup>th</sup> December sown crop and the minimum number of days were taken by crop sown on 10<sup>th</sup> January. Irrigation schedules failed to significantly influence the days to complete emergence. The interaction between the dates of sowing and different irrigation regimes was not significant.

### **4.1.2 Days to vegetative growth stage**

The days to vegetative growth were recorded when the ground cover was at least 10% as it was needed for the data used in FAO – CROPWAT model. A study of the data presented in Table 4.1 indicates that the days taken for the vegetative growth of the crop were highest during 10<sup>th</sup> November sown crop, which was followed by 10<sup>th</sup> December and 10<sup>th</sup> January sowing, respectively. The days taken to reach vegetative growth stage were not significantly affected by different irrigation scheduling methods. The interaction between the dates of sowing and the different irrigation regimes was not significant.

### **4.1.3 Days to tuber initiation stage**

The data presented in the Table 4.1 shows that the days taken to tuber initiation were significantly higher (76.3 days) in 10<sup>th</sup> November sown crop which was followed by 10<sup>th</sup> December sown crop and were lowest for the crop sown on 10<sup>th</sup> January. Under irrigation scheduling, the days to tuber initiation were significantly higher under limited irrigation (two) (66.3) and lowest under Penman monteith weather model at 50 % AWC (five) (62.1) which was at par with Penman monteith weather model at 60 % AWC (four) (62.7). The interaction between the different irrigation regimes and dates of sowing was not significant.

**Table 4.1 Effect of sowing windows and irrigation regimes on phenological stages of potato under Natural Farming**

Treatment	Days to complete emergence stage	Days to vegetative growth stage	Days to tuber initiation stage	Days to tuber bulking stage	Days to harvest stage
<b>Date of sowing</b>					
10 <sup>th</sup> November	36.8	58.2	76.3	136.8	171.6
10 <sup>th</sup> December	32.1	50.8	63.6	124.8	145.5
10 <sup>th</sup> January	22.6	43.6	52.4	98.6	121.9
SE(m)±	0.30	0.34	0.47	0.44	0.59
LSD (P=0.05)	0.87	1.00	1.37	1.28	1.73
<b>Irrigation scheduling based on ET Method</b>					
Limited irrigation (two)	30.9	51.8	66.3	123.1	148.1
Limited irrigation (three)	30.6	51.1	65.2	121.7	147.6
Penman Monteith at 60% AWC (four)	30.4	50.6	62.7	118.6	145.6
Penman Monteith at 50% AWC (five)	30.1	49.9	62.1	116.9	144.1
SE(m)±	0.34	0.39	0.54	0.50	0.68
LSD (P=0.05)	NS	NS	1.59	1.48	2.00

**4.1.4 Days to tuber bulking stage**

A close look at the Table 4.1 indicates that the days taken to tuber bulking were maximum (136.8) in 10<sup>th</sup> November sowing less and least for the crop sown on 10<sup>th</sup> January. However, days taken for tuber bulking under different irrigation scheduling methods was highest under limited irrigation(two). Under irrigation

scheduling based on different weather models, Penman monteith weather model at 50 % AWC (five) took the least number of days for tuber bulking which was at par with Penman monteith model at 60 % AWC (four). The interaction between the dates of sowing and irrigation regimes was not significant.

#### **4.1.5 Days to harvest stage**

Days taken to harvest as affected by various treatments have been presented in Table 4.1. Significantly higher number of days to harvest (171.6) were observed in the crop sown on 10<sup>th</sup> November, which was followed by 10<sup>th</sup> December and 10<sup>th</sup> January sowings, respectively. Whereas the effect of irrigation scheduling based on different weather models shows that the days taken to harvest were highest (148.1) under limited irrigation (two) treatment and the lowest under Penman monteith weather model at 50 % AWC (five) which was at par with Penman monteith weather model at 60 % AWC (four). The interaction between the various dates of sowing and irrigation regimes was not significant.

The days taken to complete emergence ranged between 23 to 37, for vegetative growth 43 to 58, for tuber initiation 52 to 76, for tuber bulking 99 to 137 and for harvest 122 to 172.

#### **4.2 Biomass studies**

The effect of the different dates of sowing and different irrigation regimes on the shoot dry matter accumulation ( $\text{kg ha}^{-1}$ ) and root dry matter accumulation ( $\text{kg ha}^{-1}$ ) at an interval of 10 days and at harvest is given in Table 4.2 and 4.3, respectively.

Table 4.2 provides the data for shoot dry matter accumulation of potato crop as effected by different treatments under Natural Farming conditions. It reveals that from 40 to 80 DAP the shoot dry matter accumulation was significantly higher under 10<sup>th</sup> January sown crop whereas in case of 10<sup>th</sup> November sowing the growth was slow in the initial 80 DAP, it was due to the prevailing low temperature during this time period. The shoot dry matter was statistically similar for 10<sup>th</sup> December and 10<sup>th</sup> January sown crop at 80 DAP. At 90 DAP significantly higher biomass was observed for 10<sup>th</sup> November sown crop. During the rest of the growth period significantly

**Table 4.2 Effect of sowing windows and irrigation regimes on shoot dry matter accumulation of potato under Natural Farming.**

Treatment	Shoot dry matter accumulation (kg ha <sup>-1</sup> )														
	30 DAP	40 DAP	50 DAP	60 DAP	70 DAP	80 DAP	90 DAP	100 DAP	110 DAP	120 DAP	130 DAP	140 DAP	150 DAP	160 DAP	At maturity
<b>Date of sowing</b>															
10 <sup>th</sup> November	21.1	41.3	80.6	122.3	233.1	537.3	821.5	940.8	1026.6	1138.4	1215.6	1288.7	1194.4	1114.7	1050.7
10 <sup>th</sup> December	24.5	59.5	106.2	149.1	258.6	560.9	809.6	925.7	996.5	1086.5	1055.3	1032.3	-	-	1015.4
10 <sup>th</sup> January	26.1	67.9	122.3	160.0	266.6	566.6	793.9	913.5	969.9	-	-	-	-	-	980.2
SE(m)±	0.47	0.75	1.19	1.42	1.70	2.25	3.45	2.60	2.82	-	-	-	-	-	3.04
LSD (P=0.05)	1.37	2.20	3.49	4.16	4.99	6.60	10.11	7.64	8.27	-	-	-	-	-	8.90
<b>Irrigation scheduling based on ET method</b>															
Limited irrigation (two)	21.4	50.4	97.1	135.5	239.1	546.8	797.4	914.4	985.9	-	-	-	-	-	998.8
Limited irrigation (three)	22.5	54.1	100.7	140.6	249.2	550.4	802.9	921.9	992.4	-	-	-	-	-	1010.2
Penman Monteith at 60%AWC (four)	25.2	58.1	105.3	148.3	258.1	559.6	815.1	934.2	1005.1	-	-	-	-	-	1024.6
Penman Monteith at 50%AWC (five)	26.4	62.5	108.5	150.7	264.9	563.2	817.9	936.1	1007.4	-	-	-	-	-	1028.1
SE(m)±	0.54	0.87	1.37	1.64	1.96	2.60	3.98	3.01	3.26	-	-	-	-	-	3.50
LSD (P=0.05)	1.58	2.54	4.03	4.80	5.76	7.63	11.67	8.82	9.55	-	-	-	-	-	10.28

higher biomass was recorded for 1<sup>st</sup> sowing. Under irrigation scheduling based on different weather models the dry matter at 40 DAP was highest under Penman monteith weather model at 50 % AWC (five) followed by Penman monteith weather model at 60% AWC (four), Limited irrigation (three) and Limited irrigations (two), respectively. For the rest of the crop growth statistically similar biomass was observed in case of Penman monteith weather model at 50 % AWC (five) and Penman monteith weather model at 60 % AWC (four). The lowest biomass was recorded under Limited irrigations (two). The interaction between the dates of sowing and the irrigation treatments was non-significant.

Table 4.3 provides the data for root dry matter accumulation of potato crop as effected by different treatments under Natural Farming conditions. At 40 DAP highest root biomass was observed in 10<sup>th</sup> January sowing which was statistically similar to 10<sup>th</sup> December sowing. At 50 DAP significantly higher biomass was recorded in case of 10<sup>th</sup> January sowing. At 60 and 80 DAP the biomass was statistically at par for 10<sup>th</sup> January and 10<sup>th</sup> December sowings. The lower root dry matter for 10<sup>th</sup> November sowing in the initial 80 DAP was due to slow growth of the crop during this time period, which was because of low temperature conditions in the months of December and January. The root dry matter at 90 DAP was highest for 10<sup>th</sup> November sown crop which was statistically at par with 10<sup>th</sup> December sowing. At 100 DAP significantly higher root biomass was observed for 1<sup>st</sup> sowing. For the rest of the crop growth period maximum root biomass was observed in case of the crop sown on 10<sup>th</sup> November which was statistically similar with 10<sup>th</sup> December sowing. Under irrigation scheduling based on different weather models the dry matter at 40 DAP was highest under Penman monteith weather model at 50 % AWC (five) which was statistically at par with Penman monteith weather model at 60 % AWC (four) treatment. The lowest biomass was recorded for Limited irrigation (two) which was statistically similar with Limited irrigation (three) treatment. For the rest of the growing period statistically similar biomass was observed in case of irrigation scheduling based on Penman monteith weather model at 50 % AWC (five) and Penman monteith weather model at 60 % AWC (four). Whereas lowest root biomass was reported under Limited irrigation (two) which was statistically at par with Limited irrigation (three) treatment. Similar findings on dry matter accumulation by

**Table 4.3 Effect of sowing windows and irrigation regimes on root dry matter accumulation of potato under Natural Farming.**

Treatment	Root dry matter accumulation (kg ha <sup>-1</sup> )														
	30 DAP	40 DAP	50 DAP	60 DAP	70 DAP	80 DAP	90 DAP	100 DAP	110 DAP	120 DAP	130 DAP	140 DAP	150 DAP	160 DAP	At harvest
<b>Date of sowing</b>															
10 <sup>th</sup> November	1.9	6.8	12.9	18.2	31.5	49.3	72.6	81.3	94.2	106.4	114.7	122.3	116.3	103.9	98.7
10 <sup>th</sup> December	6.7	12.8	19.4	24.6	34.5	50.1	71.5	78.3	93.1	102.3	109.6	101.8	-	-	96.6
10 <sup>th</sup> January	6.9	13.3	21.3	25.6	37.4	51.6	70.2	75.8	91.8	-	-	-	-	-	92.3
SE(m)±	0.09	0.18	0.23	0.36	0.40	0.55	0.53	0.90	0.61	-	-	-	-	-	0.72
LSD (P=0.05)	0.26	0.53	0.67	1.04	1.17	1.62	1.54	2.64	1.79	-	-	-	-	-	2.11
<b>Irrigation scheduling based on ET method</b>															
Limited irrigation (two)	4.4	9.9	16.2	21.1	32.1	47.2	68.6	74.7	88.9	-	-	-	-	-	92.3
Limited irrigation (three)	4.8	10.4	17.1	21.9	33.2	48.7	70.1	76.9	90.8	-	-	-	-	-	94.1
Penman Monteith at 60%AWC (four)	5.7	11.5	18.8	23.6	35.7	52.1	73.1	80.4	95.2	-	-	-	-	-	97.8
Penman Monteith at 50%AWC (five)	6.1	11.9	19.4	24.6	36.9	53.4	74.1	81.9	97.3	-	-	-	-	-	99.3
SE(m)±	0.10	0.21	0.26	0.41	0.46	0.64	0.61	1.04	0.71	-	-	-	-	-	0.83
LSD (P=0.05)	0.30	0.62	0.77	1.20	1.35	1.87	1.78	3.05	2.07	-	-	-	-	-	2.44

Gultekin et al (2021) revealed that with optimum irrigation dry matter increased in the crop. The treatments with 100% irrigations showed more biomass production when compared to 85%, 70%, 55%, 40% irrigation regimes.

### **4.3 Growth studies**

#### **4.3.1 Plant height**

The data on the mean plant height under various treatments at 60, 90 DAP (days after planting) and at harvest have been given in the table 4.4. A perusal at the table reveals that there is gradual increase in the plant height from date of planting till the harvest of the crop. At 60 DAP the maximum plant height was observed in the crop sown on 10<sup>th</sup> January sown crop which was at par with crop sown on 10<sup>th</sup> December and the minimum plant height was for the 10<sup>th</sup> November sown crop, because of the prevailing low temperature during the initial 60 days of development for 10<sup>th</sup> November sown crop. At 90 DAP the highest plant height was recorded for crop sown on 10<sup>th</sup> November which was statistically similar to crop sown on 10<sup>th</sup> December and the lowest plant height was recorded in case of 10<sup>th</sup> January sown crop. At harvest maximum plant height (40.2 cm) was observed for the 10<sup>th</sup> November sown crop which was followed by 10<sup>th</sup> December sown crop which was statistically at par to the crop sown on 10<sup>th</sup> January. Under different irrigation scheduling methods, the plant height observed at 60 DAP was highest under Penman monteith weather model at 50 % AWC (five) which was at par with Penman monteith weather model at 60 % AWC (four) and the lowest plant height was recorded under limited irrigation (two). Whereas, in case of 90 DAP and at harvest maximum plant height was under Penman monteith weather model at 50 % AWC (five) which was at par with Penman monteith weather model at 60 % AWC (four) and the plant height was minimum under Limited irrigations (two) which was statistically similar to the limited irrigation (three) treatment. Similar findings were given by Sharma (2021) that with the delay in planting the plant height showed a decreasing trend.

**Table 4.4** Effect of sowing windows and irrigation regimes on plant height of potato under Natural Farming.

Treatment	Plant height (cm)		
	60 DAP	90 DAP	At harvest
<b>Date of sowing</b>			
10 <sup>th</sup> November	15.2	27.8	40.2
10 <sup>th</sup> December	19.9	25.7	37.9
10 <sup>th</sup> January	20.3	24.4	36.7
SE(m)±	0.27	0.52	0.44
LSD (P=0.05)	0.80	1.53	1.29
<b>Irrigation scheduling based on ET Method</b>			
Limited irrigation (two)	16.5	23.5	34.1
Limited irrigation (three)	18.2	24.9	36.4
Penman Monteith at 60% AWC (four)	19.2	27.3	41.1
Penman Monteith at 50% AWC (five)	19.9	28.1	41.6
SE(m)±	0.31	0.60	0.51
LSD (P=0.05)	0.92	1.76	1.49

#### 4.3.2 Root length (Rooting depth)

A perusal of the data in Table 4.5 reveals that significantly higher root length was recorded under 10<sup>th</sup> November sown crop. In case of irrigation scheduling based on different weather models, at 90 DAP statistically similar root length was recorded under Penman monteith weather model at 50 % AWC (five) and Penman monteith weather model at 60 % AWC (four). At harvest maximum root length was observed for Penman monteith weather model at 50 % AWC (five) which was statistically at par with Penman monteith weather model at 60 % AWC (four) which in turn was statistically similar for Limited irrigation (three) treatment. These results are in close conformity with Poddar et al. (2021).

**Table 4.5** Effect of sowing windows and irrigation regimes on root length of potato under Natural Farming.

Treatment	Root length (cm)	
	90 DAP	At harvest
<b>Date of sowing</b>		
10 <sup>th</sup> November	33.37	54.35
10 <sup>th</sup> December	31.09	52.50
10 <sup>th</sup> January	29.48	51.28
SE(m)±	0.41	1.03
LSD (P=0.05)	1.21	NS
<b>Irrigation scheduling based on ET Method</b>		
Limited irrigation (two)	29.46	48.52
Limited irrigation (three)	30.49	51.76
Penman Monteith at 60% AWC (four)	32.28	53.92
Penman Monteith at 50% AWC (five)	33.06	56.64
SE(m)±	0.48	1.19
LSD (P=0.05)	1.40	3.49

### 4.3.3 Number of plants per sq. m.

A critical view of the table 4.6 revealed that the number of plants/m<sup>2</sup> were maximum (10.49) for 10<sup>th</sup> November sown crop followed by crop sown on 10<sup>th</sup> December and 10<sup>th</sup> January, respectively. Under irrigation schedules based on different weather models, the number of plants/m<sup>2</sup> were maximum under Penman monteith weather model at 50 % AWC (five) which was followed by other irrigation treatments. The number of plants/m<sup>2</sup> were not significantly impacted by different dates of sowing and irrigation regimes.

#### 4.3.4 Number of leaves per plant

A close view of the data presented in table 4.6 indicates that the number of leaves increased till harvest. At 60 DAP the number of leaves were maximum for the crop sown on 10<sup>th</sup> January which was followed by crop sown on 10<sup>th</sup> December. The minimum number of leaves were observed in the crop sown on 10<sup>th</sup> November, because of the prevailing low temperature during the initial 60 days of development which resulted in slow growth of the crop. The number of leaves were maximum at 90 DAP for crop sown on 10<sup>th</sup> November followed by crop sown on 10<sup>th</sup> December, which was statistically similar to the crop sown on 10<sup>th</sup> January. At harvest the

**Table 4.6 Effect of sowing windows and irrigation regimes on number of plants/m<sup>2</sup> and number of leaves/ plant under Natural Farming.**

Treatment	No. of plants/m <sup>2</sup>	No. of leaves/ plant		
		60 DAP	90 DAP	At harvest
<b>Date of sowing</b>				
10 <sup>th</sup> November	10.49	4.1	10.6	12.4
10 <sup>th</sup> December	10.75	5.3	10.2	13.4
10 <sup>th</sup> January	10.32	5.7	9.9	13.5
SE(m)±	0.22	0.08	0.16	0.20
LSD (P=0.05)	NS	0.23	0.47	0.58
<b>Irrigation scheduling based on ET Method</b>				
Limited irrigation (two)	10.33	4.18	9.10	12.21
Limited irrigation (three)	10.48	4.93	9.95	12.41
Penman Monteith at 60% AWC (four)	10.60	5.40	10.89	13.65
Penman Monteith at 50% AWC (five)	10.67	5.50	11.12	14.14
SE(m)±	0.26	0.09	0.18	0.23
LSD (P=0.05)	NS	0.26	0.54	0.67

maximum number of leaves were seen in the crop sown on 10<sup>th</sup> January which was statistically at par to the crop sown on 10<sup>th</sup> December. Under irrigation scheduling based on different weather models, Penman monteith weather model at 50% AWC (five) recorded maximum number of leaves at 60, 90 DAP and at harvest which was statistically similar to Penman monteith weather model at 60 % AWC (four). The number of leaves/plant at 60 and 90 DAP were minimum under Limited irrigations (two). At harvest, the minimum number was recorded under Limited irrigations (two) which was statistically similar to the limited irrigation (three) treatment.

#### **4.3.5 Leaf area index**

The data presented in the Table 4.7 revealed that there was a gradual increase in the LAI till 90 DAP and thereafter decreased during rest of the crop growth duration. The LAI observed to be significantly different for all dates of sowing. At 60 DAP it was highest for 10<sup>th</sup> January sown crop while at harvest it was highest for 10<sup>th</sup> November sown crop. Whereas, in case of irrigation scheduling based on different weather models, LAI at 60 DAP was recorded to be highest under Penman monteith weather model at 50 % AWC (five) which was at par with Penman monteith weather model at 60% AWC (four) which in turn was statistically at par with limited irrigation (three). The minimum LAI was observed under limited irrigation (two). At 90 DAP the highest value was under Penman monteith weather model at 50 % AWC (five) which was statistically at par with Penman monteith weather model at 60% AWC (four). The maximum value for LAI at harvest was observed under Penman monteith weather model at 50 % AWC (five) which was at par with Penman monteith weather model at 60% AWC (four), followed by Limited irrigations (three). The lowest value was recorded under Limited irrigations (two). Gupta (2017) also found out that early sown crop has higher LAI in comparison to late sown crop.

**Table 4.7 Effect of sowing windows and irrigation regimes on leaf area index of the potato under Natural Farming.**

Treatment	LAI		
	60 DAP	90 DAP	At harvest
<b>Date of sowing</b>			
10 <sup>th</sup> November	1.51	3.08	2.73
10 <sup>th</sup> December	2.03	2.85	2.54
10 <sup>th</sup> January	2.21	2.76	2.29
SE(m)±	0.05	0.05	0.03
LSD (P=0.05)	0.15	0.14	0.09
<b>Irrigation scheduling based on ET Method</b>			
Limited irrigation (two)	1.64	2.59	2.29
Limited irrigation (three)	1.88	2.78	2.41
Penman Monteith at 60% AWC (four)	2.03	3.04	2.59
Penman Monteith at 50% AWC (five)	2.11	3.17	2.78
SE(m)±	0.06	0.05	0.04
LSD (P=0.05)	0.17	0.16	0.11

#### 4.4 Yield attributes

The yield attributes studied for the potato crop were number of shoots/plant, average number of tubers/ plant, average tuber weight, tuber grading and tuber yield.

##### 4.4.1 Number of shoots per plant

The observation recorded in the Table 4.8 revealed that the number of shoots per plant were recorded to be maximum in the 10<sup>th</sup> November sown crop which was followed by 10<sup>th</sup> December and 10<sup>th</sup> January sowing. Among different irrigation regimes the highest number was observed under Penman monteith weather model at 50 % AWC (five) which was followed by Penman monteith weather model at 60%

AWC (four). Whereas, the lowest number of shoots per plant were observed under Limited irrigations (two). These results are in close conformity with the findings of Narayan *et al.* (2009) who have also observed that number of shoots in the crop sown earlier were more in comparison to the late sown crop.

#### **4.4.2 Number of tubers per plant**

The data for the average number of tubers per plant is presented in the Table 4.8. A perusal of the table revealed that the highest number of tubers were recorded in the 10<sup>th</sup> November sowing which was statistically similar to the crop sown on 10<sup>th</sup> December which in turn was statistically at par with the crop sown on 10<sup>th</sup> January. Under irrigation scheduling based on different weather models, the maximum number of tubers were seen under Penman monteith weather model at 50 % AWC (five) which was at par with the Penman monteith weather model at 60% AWC (four). Whereas, lowest number was observed under limited irrigation (two) treatment which was statistically similar with the limited irrigation (three) treatment. Similar observations were recorded by Dash *et al.* (2018) that the number of tubers were more in early sown crop as compared to late sown crop.

#### **4.4.3 Average tuber weight**

A close look at the data given in Table 4.8 revealed that the average tuber weight was observed to be significantly higher in the crop sown on 10<sup>th</sup> November followed by crop sown on 10<sup>th</sup> December and 10<sup>th</sup> January sown crop, respectively. Under irrigation scheduling based on different weather models, maximum tuber weight was observed in case of Penman monteith weather model at 50 % AWC (five) which was at par with the Penman monteith weather model at 60% AWC (four), followed by Limited irrigations (three) treatment. The minimum tuber weight was observed under Limited irrigations (two) treatment. Ravikant and Chadha (2005) also found out that the tuber weight was maximum for the crop that was planted earlier compared to the late sown crop.

**Table 4.8** Effect of sowing windows and irrigation regimes on the no. of shoots/ plant, average no. of tubers/ plant and average tuber weight under natural farming environment.

Treatments	No. of shoots/plant	Average no. of tubers/plant	Average tuber weight(g)
<b>Date of sowing</b>			
10 <sup>th</sup> November	2.88	5.04	28.19
10 <sup>th</sup> December	2.62	4.87	26.92
10 <sup>th</sup> January	2.38	4.73	25.38
SE(m)±	0.05	0.06	0.25
LSD (P=0.05)	0.16	0.18	0.74
<b>Irrigation scheduling based on ET Method</b>			
Limited irrigation (two)	1.47	4.51	23.37
Limited irrigation (three)	2.30	4.69	24.68
Penman Monteith at 60% AWC (four)	3.21	5.08	29.27
Penman Monteith at 50% AWC (five)	3.52	5.23	30.01
SE(m)±	0.06	0.07	0.29
LSD (P=0.05)	0.18	0.21	0.85

#### 4.4.4 Grading

A perusal of the data presented in the Table 4.9 revealed that the maximum yield for the large size tubers was recorded in 10<sup>th</sup> November sown crop. The yield was minimum for 10<sup>th</sup> January sowing. Under irrigation scheduling based on different weather models, the highest yield for large size tubers was recorded in case of Penman monteith weather model at 50 % AWC (five) which was at par with the Penman monteith weather model at 60% AWC (four). For medium size tubers significantly higher yield was observed in 10<sup>th</sup> November sowing which was followed

by crop sown on 10<sup>th</sup> December and 10<sup>th</sup> January, respectively. Under irrigation scheduling based on different weather models, the maximum yield was recorded in case of Penman monteith weather model at 50 % AWC (five) which was statistically similar with the Penman monteith weather model at 60% AWC (four). In case of the small size tubers the highest yield was recorded under the 10<sup>th</sup> November sowing followed by 10<sup>th</sup> December sowing which was at par with the crop sown on 10<sup>th</sup> January. Amongst the irrigation scheduling methods, the yield was recorded to be highest under Penman monteith weather model at 50 % AWC (five) which was at par with the Penman monteith weather model at 60% AWC (four). The tuber size and weight was also affected by the number of irrigations under Palampur conditions as reported by Sanjeev (2018).

#### **4.4.5 Tuber yield**

An examination of the data given in the Table 4.9 revealed that the highest tuber yield to the tune of 125.5 q/ha was recorded in the crop sown on 10<sup>th</sup> November which was followed by the crop sown on 10<sup>th</sup> December and 10<sup>th</sup> January, respectively. The crop sown on 10<sup>th</sup> November provided the highest yield which might be due to the following factors *viz.* more number of shoots, more number of tubers and periodic dry matter accumulation. Under irrigation scheduling based on different weather models, the tuber yield was maximum under Penman monteith weather model at 50 % AWC (five) (123.4 q/ha) which was statistically similar to Penman monteith weather model at 60% AWC (four) (120.9 q/ha). The yield was minimum under Limited irrigations (two) (100.2 q/ha). Gogoi *et al.* (2020) have also reported higher tuber yield in timely sown crop compared to the late planting.

#### **4.5 Validation of FAO – CROPWAT model**

The evidence for the validation of the model has been presented in Table 4.10. The FAO – CROPWAT model was validated for the reference evapotranspiration with the actual evapotranspiration calculated from the field water balance and the RMSE variation was found to be 12.87, 12.18 and 12.47 for 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sowings, respectively. The validation of model was done to find the futuristic crop water requirement for the potato crop with the elevated temperature and change in rainfall.

**Table 4.9** Effect of sowing windows and irrigation regimes on tuber yield (q/ha) and its grading under Natural Farming.

Treatments	Tuber yield (q/ha)	Grading (q/ha)		
		>75g	50-75g	<50g
<b>Date of sowing</b>				
10 <sup>th</sup> November	125.5	22.5	68.3	33.7
10 <sup>th</sup> December	111.9	19.2	63.5	29.2
10 <sup>th</sup> January	103.1	17.7	58.8	26.6
SE(m)±	1.00	0.44	0.93	0.90
LSD (P=0.05)	2.94	1.30	2.73	2.64
<b>Irrigation scheduling based on ET Method</b>				
Limited irrigation (two)	100.2	17.3	57.6	25.3
Limited irrigation (three)	109.6	19.1	61.9	28.4
Penman Monteith at 60% AWC (four)	120.9	21.2	66.7	32.6
Penman Monteith at 50% AWC (five)	123.4	21.9	67.2	34.3
SE(m)±	1.16	0.51	1.07	1.04
LSD (P=0.05)	3.39	1.5	3.15	3.05

**Table 4.10 Validation of the FAO-CROPWAT model**

<b>Month (For 1<sup>st</sup> DOS)</b>	<b>Ref ET CROPWAT model</b>	<b>AET field water balance method</b>
November	1.93	2.18
December	1.35	1.32
January	1.23	1.45
February	2.03	1.58
March	3.82	3.27
April	5.32	5.02
	<b>RMSE</b>	<b>12.87%</b>

<b>Month (For 2<sup>nd</sup> DOS)</b>	<b>Ref ET CROPWAT model</b>	<b>AET field water balance method</b>
December	1.31	0.99
January	1.23	1.45
February	2.03	1.84
March	3.82	3.43
April	5.32	4.62
May	4.86	4.75
	<b>RMSE</b>	<b>12.18%</b>

<b>Month (For 3<sup>rd</sup> DOS)</b>	<b>Ref ET CROPWAT model</b>	<b>AET field water balance method</b>
January	1.23	1.78
February	2.03	2.17
March	3.82	3.52
April	5.32	4.62
May	4.93	4.40
	<b>RMSE</b>	<b>12.47%</b>

## 4.6 Estimation of evapotranspiration

### 4.6.1 Estimated Reference Evapotranspiration ( $ET_o$ ).

The estimation of  $ET_o$  for the entire crop period was done by using the FAO-CROPWAT model. Actual ET was computed using field water balance approach for different irrigation levels. The soil moisture was taken at an interval of 10 days, before and after irrigations and rainfall. A close examination of the data in Table 4.11 revealed that the actual evapotranspiration showed an increasing trend with the increase in the number of irrigations. The maximum AET for the first date of sowing was recorded under irrigation scheduling based on Penman monteith weather model at 50 % AWC (five) which was 419.74. The AET for Limited irrigations (two), limited irrigations(three) and Penman monteith weather model at 60 % AWC (four) were 378.35 mm, 389.34 mm and 399.96 mm, respectively. The estimated  $ET_o$  by CROPWAT for 10<sup>th</sup> November sowing was 432.45 mm. For 2<sup>nd</sup> date of sowing the maximum AET was 382.18 mm under irrigation scheduling based on Penman monteith weather model at 50 % AWC (five). The AET for Limited irrigations (two), limited irrigations(three) and Penman monteith weather model at 60 % AWC (four) were 348.63 mm, 358.72 mm and 370.99 mm, respectively. The  $ET_o$  estimated by CROPWAT was 421.25 mm. In case of 3<sup>rd</sup> date of sowing the AET under irrigation scheduling based on Penman monteith weather model at 50 % AWC (five) was 387.24 mm which was maximum. Whereas, under Limited irrigations (two), limited irrigations(three) and Penman monteith weather model at 60 % AWC (four) the AET recorded were 350.30 mm, 363.01 mm and 376.92 mm, respectively. The  $ET_o$  estimated by CROPWAT was 406.29 mm. Similar findings were reported by Dar et al. (2017) at Ludhiana that determined Penman-Monteith as the most accurate model for predicting AET.

### 4.6.2 Estimated Crop Evapotranspiration ( $ET_c$ )

The crop evapotranspiration was calculated by using the crop coefficients ( $K_c$ ) taken from FAO for different stages of crop growth. A cursory glance of the data presented in the Table 4.12 revealed that the crop evapotranspiration increased gradually with an increase in number of irrigations. In case of 10<sup>th</sup> November sown crop the  $ET_c$  was highest (367.50 mm) under Penman monteith weather model at 50 % AWC (five) and lowest (330.34 mm) under Limited irrigations (two). The  $ET_c$  for

**Table 4.11 Estimation of ET<sub>o</sub> (mm) under various irrigation regimes and by CROPWAT model (mm).**

Month	Field water balance				CROPWAT
	2 Irri.	3 Irri.	4 Irri.	5 Irri.	
<b>10<sup>th</sup> November</b>					
November, 2021	2.18	2.18	2.18	2.18	1.93
December, 2021	1.32	1.32	1.32	1.32	1.32
January, 2022	1.46	1.46	1.45	1.45	1.23
February, 2022	1.58	1.58	1.58	1.58	2.03
March, 2022	2.57	2.72	2.98	3.17	3.82
April, 2022	4.12	4.31	4.51	5.02	5.32
<b>Total</b>	<b>378.35</b>	<b>389.34</b>	<b>399.96</b>	<b>419.74</b>	<b>432.45</b>
<b>10<sup>th</sup> December</b>					
December, 2021	0.99	0.99	0.99	0.99	1.31
January, 2022	1.45	1.45	1.45	1.45	1.23
February, 2022	1.84	1.84	1.81	1.84	2.03
March, 2022	2.81	3.07	3.28	3.43	3.82
April, 2022	4.15	4.21	4.43	4.62	5.32
May, 2022	4.75	4.75	4.75	4.75	4.86
<b>Total</b>	<b>348.63</b>	<b>358.72</b>	<b>370.99</b>	<b>382.18</b>	<b>421.25</b>
<b>10<sup>th</sup> January</b>					
January, 2022	1.78	1.78	1.72	1.78	1.23
February, 2022	2.17	2.17	2.17	2.17	2.03
March, 2022	2.88	3.29	3.52	3.52	3.82
April, 2022	4.05	4.05	4.32	4.62	5.32
May, 2022	4.40	4.40	4.40	4.40	4.93
<b>Total</b>	<b>350.30</b>	<b>363.01</b>	<b>376.92</b>	<b>387.24</b>	<b>406.29</b>

**Table 4.12 Estimation of crop water requirement (ETc) (mm) under various irrigation regimes and by CROPWAT model (mm).**

Month	2 Irri.	3 Irri.	4 Irri.	5 Irri.	CROPWAT
<b>10<sup>th</sup> November</b>					
10 <sup>th</sup> – 30 <sup>th</sup> November, 2021	1.09	1.09	1.09	1.09	0.97
1 <sup>st</sup> – 10 <sup>th</sup> December, 2021	0.66	0.66	0.66	0.66	0.68
12 <sup>th</sup> – 31 <sup>st</sup> December, 2021	1.52	1.52	1.52	1.52	1.55
1 <sup>st</sup> – 22 <sup>nd</sup> January, 2022	1.68	1.68	1.67	1.67	1.41
23 <sup>rd</sup> - 31 <sup>st</sup> January, 2022	1.68	1.68	1.67	1.67	1.41
February, 2022	1.82	1.82	1.82	1.82	2.33
1 <sup>st</sup> – 17 <sup>th</sup> March, 2022	2.96	3.13	3.43	3.64	4.39
18 <sup>th</sup> – 31 <sup>st</sup> March, 2022	1.93	2.04	2.24	2.38	2.87
1 <sup>st</sup> – 29 <sup>th</sup> April, 2022	3.09	3.23	3.38	3.77	3.99
<b>Total</b>	<b>330.34</b>	<b>338.93</b>	<b>350.75</b>	<b>367.50</b>	<b>398.12</b>
<b>10<sup>th</sup> December</b>					
10 <sup>th</sup> – 31 <sup>st</sup> December, 2021	0.50	0.50	0.50	0.50	0.66
1 <sup>st</sup> – 7 <sup>th</sup> January, 2022	0.73	0.73	0.73	0.73	0.62
8 <sup>th</sup> – 31 <sup>st</sup> January, 2022	1.67	1.67	1.67	1.67	1.41
1 <sup>st</sup> – 9 <sup>th</sup> February, 2022	2.12	2.12	2.08	2.13	2.33
10 <sup>th</sup> – 28 <sup>th</sup> February, 2022	2.12	2.12	2.08	2.13	2.33
1 <sup>st</sup> – 29 <sup>th</sup> March, 2022	3.23	3.53	3.77	3.94	4.39
30 <sup>th</sup> – 31 <sup>st</sup> March, 2022	2.11	2.30	2.46	2.57	2.87
April, 2022	3.11	3.16	3.32	3.47	3.99
1 <sup>st</sup> – 4 <sup>th</sup> May, 2022	3.56	3.56	3.56	3.56	3.65
<b>Total</b>	<b>320.88</b>	<b>331.32</b>	<b>342.49</b>	<b>353.38</b>	<b>385.11</b>
<b>10<sup>th</sup> January</b>					
10 <sup>th</sup> – 31 <sup>st</sup> January, 2022	0.71	0.71	0.69	0.71	0.49
1 <sup>st</sup> – 3 <sup>rd</sup> February, 2022	0.87	0.87	0.87	0.87	0.81
4 <sup>th</sup> – 28 <sup>th</sup> February, 2022	2.49	2.49	2.49	2.49	2.33
1 <sup>st</sup> – 4 <sup>th</sup> March, 2022	3.48	3.78	4.05	4.05	4.39
5 <sup>th</sup> – 31 <sup>st</sup> March, 2022	3.48	3.78	4.05	4.05	4.39
1 <sup>st</sup> – 9 <sup>th</sup> April, 2022	4.45	4.66	4.97	5.31	6.12
10 <sup>th</sup> – 30 <sup>th</sup> April, 2022	2.32	2.43	2.59	2.77	3.19
1 <sup>st</sup> – 9 <sup>th</sup> May, 2022	2.64	2.64	2.64	2.64	2.96
<b>Total</b>	<b>301.08</b>	<b>314.41</b>	<b>328.47</b>	<b>335.07</b>	<b>356.26</b>

Limited irrigation (three) and Penman monteith weather model at 60 % AWC (four) were 338.93 mm and 350.75 mm respectively. The  $ET_c$  estimated by CROPWAT was 398.12 mm. For of 2<sup>nd</sup> date of sowing the  $ET_c$  values under different irrigation scheduling methods were 320.88 mm, 331.32 mm, 342.49 mm and 353.38 mm for Limited irrigations (two), Limited irrigation (three), Penman monteith weather model at 60 % AWC (four) and Penman monteith weather model at 50 % AWC (five), respectively. The value being highest under Penman monteith weather model at 50 % AWC (five). The  $ET_c$  calculated by CROPWAT was 385.11 mm for 10<sup>th</sup> December sown crop. The maximum  $ET_c$  for 10<sup>th</sup> January was 335.07 which was under Penman monteith weather model at 50 % AWC (five) treatment. The  $ET_c$  values for Limited irrigation (two), Limited irrigation (three) and Penman monteith weather model at 60 % AWC (four) were 301.08 mm, 314.41 mm and 328.47 mm respectively. The CROPWAT  $ET_c$  for the crop duration was 356.26 mm. Sharma (2021) conducted a study on crop ET under different irrigation regimes and discovered that  $ET_c$  was higher for the crop with more number of irrigations.

#### **4.6.3 Irrigation scheduling**

Table 4.13 contains information regarding various irrigation schedules followed during the crop growth period for different dates of sowing. The water used for Limited irrigation (two), Limited irrigation (three), Penman monteith weather model at 60 % AWC (four) and Penman monteith weather model at 50 % AWC (five) was 120 mm, 180 mm, 240 mm and 300 mm, respectively. The water used for each irrigation was 60 mm. A close look at the table revealed that for first date of sowing the irrigation was provided at an interval of 108 days in case of Limited irrigation (two) treatment, 99 and 10 days interval under Limited irrigation (three) treatment. Under irrigation scheduling based on Penman monteith weather model at 60 % AWC (four) there was a gap of 92, 12 and 15 days respectively. In case of irrigation scheduling based on Penman monteith weather model at 50 % AWC (five) there was gap of 87, 12, 8 and 7 days respectively. There was an interval of 108 days under Limited irrigations (two) treatment, 98 and 11 days under Limited irrigations (three); 85, 10 and 19 days gap under irrigation scheduling based on Penman monteith weather model at 60 % AWC (four) and 83, 10, 10 and 7 days interval in case of

**Table 4.13 Irrigation scheduling under different treatments**

<b>Treatments</b>	<b>Irrigations scheduling by different treatments</b>					<b>Water used (mm)</b>
<b>10<sup>th</sup> November</b>						
Limited irrigation (two)	22-12-21			10-04-22		<b>120</b>
Limited irrigation (three)	22-12-21		31-03-22	10-04-22		<b>180</b>
Penman Monteith at 60%AWC (four)	12-12-21	15-03-22	27-03-22		12-04-22	<b>240</b>
Penman Monteith at 50%AWC (five)	18-12-21	16-03-22	29-03-22	07-04-22	15-04-22	<b>300</b>
<b>10<sup>th</sup> December</b>						
Limited irrigation (two)	22-12-22			10-04-22		<b>120</b>
Limited irrigation (three)	22-12-22		28-03-22	10-04-22		<b>180</b>
Penman Monteith at 60%AWC (four)	17-12-22	13-03-22	23-03-22		12-04-22	<b>240</b>
Penman Monteith at 50%AWC (five)	22-12-22	16-03-22	26-03-22	07-04-22	15-04-22	<b>300</b>
<b>10<sup>th</sup> January</b>						
Limited irrigation (two)	20-02-22			10-04-22		<b>120</b>
Limited irrigation (three)	20-02-22		31-03-22	10-04-22		<b>180</b>
Penman Monteith at 60%AWC (four)	16-02-22	14-03-22	23-03-22		12-04-22	<b>240</b>
Penman Monteith at 50%AWC (five)	18-02-22	16-03-22	28-03-22	07-04-22	15-04-22	<b>300</b>

irrigation scheduling based on Penman monteith weather model at 50 % AWC (five) for 2<sup>nd</sup> date of sowing. The major gap between 1<sup>st</sup> and 2<sup>nd</sup> irrigation for all the treatments under 10<sup>th</sup> November and 10<sup>th</sup> December sowings was due to sufficient amount of rainfall in the months of January and February. For 10<sup>th</sup> January sown crop there was a gap of 48 days under Limited irrigations (two), 39 and 10 days interval under Limited irrigations (three). In case of irrigation scheduling based on Penman monteith weather model at 60 % AWC (four) and Penman monteith weather model at 50 % AWC (five) the interval was 26, 9 & 20 days and 25,12, 10 and 7 days, respectively. The table 4.13 mentions the specific dates pertaining to the time intervals. The ET values and the amount of rainfall that occurred during the crop duration were used to determine the schedules.

#### **4.6.4 Soil water content**

The moisture content was determined at an interval of 10 days, before and after irrigations and before and after rainfall at two different depths viz. 0-15cm and 15-30cm. A close examination of the data presented in the table 4.14 revealed that the moisture content did not have any uniform distribution due to irregular pattern of the rainfall during crop growth period. For 1<sup>st</sup> date of sowing the moisture was in the range of 18.2-36.9% under different irrigation regimes. The moisture content varied between 17.7- 23.9.3% before irrigation and 22.5-31.8% after irrigations for different treatments. After 30 DAP, the moisture content under different irrigation treatments ranged from 21-25%. In case of 10<sup>th</sup> December sown crop the moisture content varied between 17.9-31.9% for the entire crop growth period under different irrigation regimes. The soil moisture was in the range of 17.5-22.9% before irrigation and 22.3-31.4% after irrigation. At 30 DAP the soil moisture varied between 28-29%. In case of crop sown on 10<sup>th</sup> January the soil moisture was in the range of 18.1-35.6% during the entire crop duration. Under different treatments the soil moisture ranged between 18.2-22.6% before irrigation and 21-29% after irrigation. At 30 DAP the moisture content was between 18-23% under irrigation scheduling based on different weather models. It was observed that the amount of soil moisture increased with both the depth and the frequency of irrigation. The irrigation given was 60mm for all treatments. The crop was never subjected to permanent wilting point during the entire crop growth duration. Pareek et al. (2022) observed that the soil moisture content was more in sub surface layer (0.15-0.30 m) than surface layer (0.00-0.15 m).

**Table 4.14 Soil moisture content (% by weight) during the entire crop growth period.**

Treatment	Depth of sowing	Soil moisture content (%)																	
		10/11	20/11	30/11	10/12	20/12	30/12	09/01	19/01	29/01	08/02	18/02	28/02	10/03	20/03	30/03	09/04	19/04	29/04
<b>10<sup>th</sup> November</b>																			
Limited irrigation (two)	0-15 cm	35.4	31.6	25.5	21.8	18.2	29.5	26.9	22.7	29.8	31.7	26.7	33.4	29.4	25.6	19.2	28.9	22.7	18.2
	15-30 cm	36.5	32.4	26.8	22.9	19.5	30.9	27.5	23.8	31.2	32.6	27.9	34.5	30.8	26.7	20.8	29.7	23.2	19.5
Limited irrigation (three)	0-15 cm	35.8	32.2	25.8	21.9	18.7	30.1	27.2	22.8	30.4	31.9	28.4	33.9	30.4	25.7	30.4	29.8	22.8	18.9
	15-30 cm	36.6	32.7	26.5	22.7	19.9	31.2	27.4	23.4	31.5	32.8	29.3	34.8	31.2	26.9	31.9	30.6	23.2	19.4
Penman monteith at 60% AWC (four)	0-15 cm	35.9	32.9	26.2	23.6	29.7	27.9	28.3	24.6	28.9	32.8	28.6	33.8	30.9	28.9	30.6	24.7	29.7	21.4
	15-30 cm	36.8	33.6	27.5	24.8	30.6	28.6	29.7	25.8	29.4	33.7	29.2	34.5	31.8	30.2	31.9	25.2	30.9	22.5
Penman monteith at 50% AWC (five)	0-15 cm	36.2	33.8	26.8	23.9	29.8	28.2	28.7	25.1	29.2	32.9	29.1	34.2	31.3	29.2	31.2	29.5	30.7	22.3
	15-30 cm	36.9	34.5	27.6	25.1	30.8	28.9	29.6	25.8	30.8	33.4	29.8	34.9	32.5	29.9	31.8	30.5	31.5	23.4

Treatment	Depth of sowing	Soil moisture content (%)															
		10/12	20/12	30/12	09/01	19/01	29/01	08/02	18/02	28/02	10/03	20/03	30/03	09/04	19/04	29/04	08/05
<b>10<sup>th</sup> December</b>																	
Limited irrigation (two)	0-15 cm	29.8	25.7	29.7	28.9	30.6	29.9	29.2	25.7	28.8	22.1	31.8	28.8	24.9	21.9	19.2	17.9
	15-30 cm	30.5	26.9	30.4	29.6	31.9	30.7	29.9	26.6	29.5	23.2	32.4	29.9	26.2	23.1	20.8	18.6
Limited irrigation (three)	0-15 cm	30.2	25.9	29.8	29.6	30.9	30.6	29.8	26.2	29.4	22.8	18.5	29.8	30.7	25.9	22.7	18.2
	15-30 cm	30.9	26.6	30.4	31.2	31.7	31.9	31.8	27.9	30.6	23.6	19.8	30.7	31.6	26.6	23.5	18.9
Penman monteith at 60% AWC ( four)	0-15 cm	29.8	28.8	24.5	28.7	26.8	27.2	28.6	24.6	30.9	24.1	28.7	29.5	22.2	28.9	24.1	20.9
	15-30 cm	29.9	29.6	25.4	29.4	27.4	28.1	29.4	25.8	31.7	25.5	29.9	30.7	23.1	29.5	24.9	22.1
Penman monteith at 50% AWC ( five)	0-15 cm	30.7	24.5	29.5	29.1	26.9	27.5	28.8	24.6	31.2	24.5	29.8	30.5	28.9	29.5	25.6	21.5
	15-30 cm	31.5	25.1	30.6	29.9	27.7	28.4	29.6	25.5	31.9	26.2	30.8	31.2	29.8	30.9	26.2	22.4

Treatment	Depth of sowing	Soil moisture content (%)													
		10/01	20/01	30/01	9/02	19/02	01/03	11/03	21/03	31/03	10/04	20/04	30/04	10/05	
<b>10<sup>th</sup> January</b>															
Limited irrigation (two)	0-15 cm	28.7	26.5	22.5	18.1	27.6	28.6	24.2	20.2	18.8	28.8	24.8	20.1	18.4	
	15-30 cm	29.5	27.4	23.5	19.2	28.8	29.3	25.8	21.1	19.5	29.7	25.5	21.6	19.2	
Limited irrigation (three)	0-15 cm	28.9	26.7	23.9	18.4	28.2	28.9	24.8	28.4	22.5	18.9	29.4	22.2	18.6	
	15-30 cm	29.7	27.5	24.6	19.6	28.9	29.4	25.5	29.3	23.6	19.6	30.2	22.9	19.3	
Penman monteith at 60% AWC ( four)	0-15 cm	29.2	27.1	24.9	22.1	29.1	28.7	24.7	29.6	28.3	20.1	28.8	23.3	19.5	
	15-30 cm	30.3	28.8	25.8	22.8	29.9	29.8	25.2	30.1	29.2	21.3	29.7	24.1	20.6	
Penman monteith at 50% AWC ( five)	0-15 cm	29.4	27.2	24.5	21.9	30.2	28.9	24.5	27.4	28.5	29.7	33.5	24.4	19.8	
	15-30 cm	29.9	28.2	25.3	22.6	31.3	30.1	25.7	28.1	29.3	30.5	35.6	25.2	20.8	

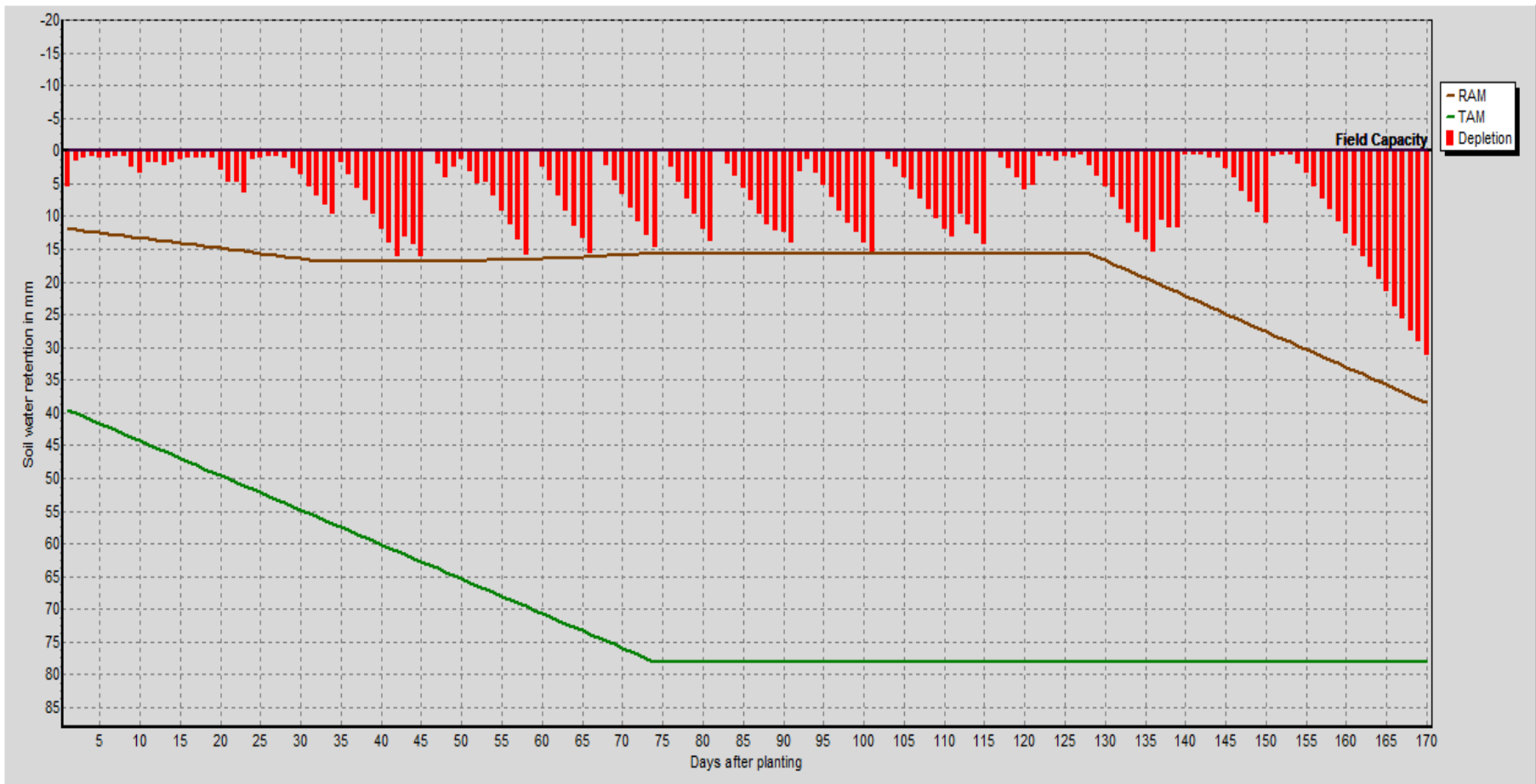


Fig. 4.1. Soil moisture depletion for 10<sup>th</sup> November, 2021 sowing.

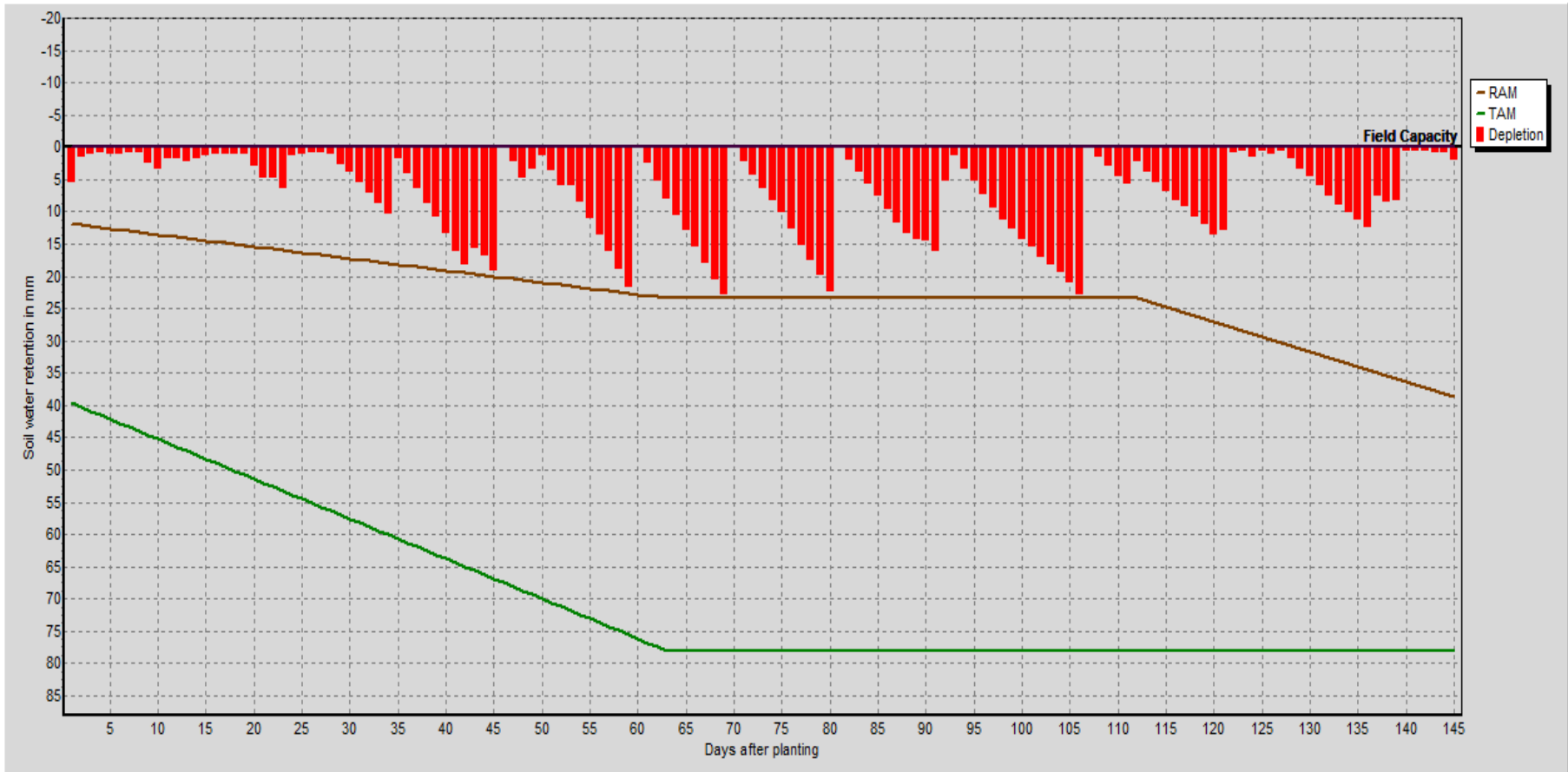
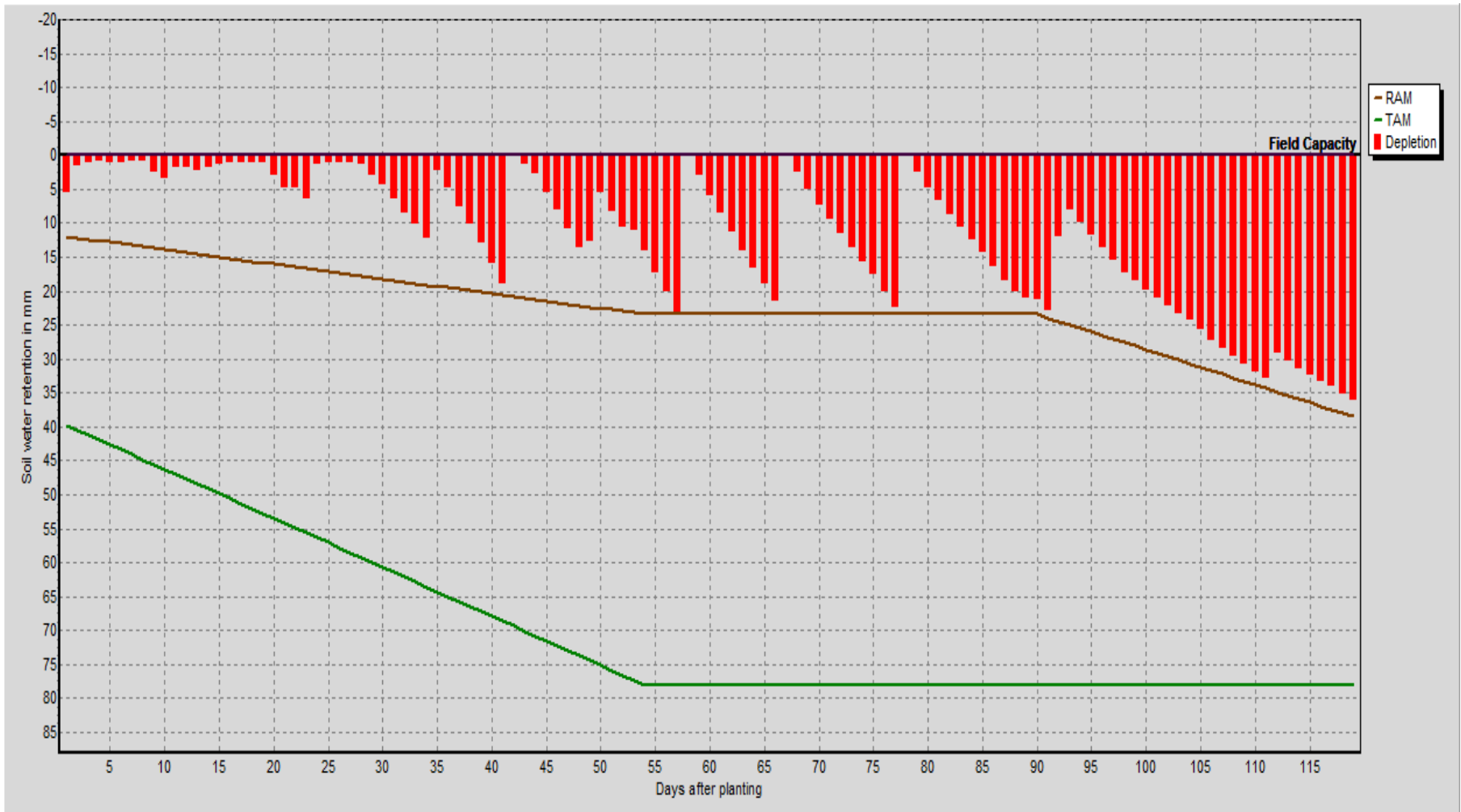


Fig. 4.2. Soil moisture depletion for 10<sup>th</sup> December, 2021 sowing.



**Fig. 4.3. Soil moisture depletion for 10<sup>th</sup> January, 2022 sowing.**

The Fig 4.1, 4.2 and 4.3 show the depletion of soil moisture of 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sown crop, respectively. The graphs of soil moisture during the crop growth taken from FAO – CROPWAT models are shown in the figures. The graphs depict that the soil moisture had never gone below the total available moisture. The readily available moisture is the difference between the field capacity and the critical moisture content. The critical moisture is taken at the 50% depletion of the field capacity which is taken to apply the irrigation to the crop so that the crop doesn't deplete below the readily available moisture.

#### **4.6.5 Total rainfall and effective rainfall**

The effective rainfall is that part of the total rainfall which is available to the crops for their use. The effective rainfall was taken from FAO – CROPWAT model. A perusal of Table 4.15 revealed that in case of first date of sowing the total rainfall and effective rainfall was 331.8 mm and 208.7 mm, respectively. For the 2<sup>nd</sup> date of sowing the total rainfall was 313.4 mm and effective rainfall was 191.2 mm. In case of crop sown on 10<sup>th</sup> January the total and effective rainfall was 172.5 and 144.9 mm, respectively. With increase in the amount of rainfall the effective rainfall decreased due to more runoff and deep percolation losses.

#### **4.6.6 Water footprints**

Table 4.16 provides information regarding the irrigation water footprints for different dates of sowing and irrigation scheduling based on different weather models. The irrigation water footprints were lowest in case of 10<sup>th</sup> November sowing with a value of 241. Whereas, for 10<sup>th</sup> December and 10<sup>th</sup> January sown crop water footprints were 268 and 281, respectively. Under irrigation scheduling based on different weather models, they were 116, 164, 198 and 243 for Limited irrigation (two), Limited irrigation (three), Penman monteith weather model at 60 % AWC (four) and Penman monteith weather model at 50 % AWC (five), respectively. Sharma (2021) also found that Penman monteith method was best for calculation of crop water requirement of potato crop.

**Table 4.15 Total and effective rainfall during the crop growth period.**

<b>Month</b>	<b>Total Rainfall (mm)</b>	<b>Effective Rainfall (mm)</b>	<b>Effective Rainfall (%)</b>
<b>10<sup>th</sup> November</b>			
November, 2021	0.0	0.0	0
December, 2021	23.4	21.6	77.59
January, 2022	216.8	107.0	49.35
February, 2022	67.8	56.7	83.63
March, 2022	9.4	9.0	95.74
April, 2022	14.8	14.2	95.95
<b>Total</b>	<b>331.8</b>	<b>208.7</b>	<b>62.89</b>
<b>10<sup>th</sup> December</b>			
December, 2021	4.6	4.1	89.13
January, 2022	216.8	107.0	49.35
February, 2022	67.8	56.7	83.63
March, 2022	9.4	9.0	95.74
April, 2022	14.8	14.2	95.95
May, 2022	0.0	0.0	0
<b>Total</b>	<b>313.4</b>	<b>191.2</b>	<b>61.01</b>
<b>10<sup>th</sup> January</b>			
January, 2022	72.6	58.6	80.72
February, 2022	67.8	56.7	83.63
March, 2022	9.4	9.0	95.74
April, 2022	14.8	14.2	95.95
May, 2022	7.9	6.4	81.01
<b>Total</b>	<b>172.5</b>	<b>144.9</b>	<b>84</b>

**Table 4.16 Effect of sowing windows and irrigation regimes on water footprints of potato crop under Natural Farming environment.**

<b>Irrigation scheduling</b>	<b>Yield (kg)</b>	<b>Irri. water (mm)</b>	<b>Irri. water ('000 L)</b>	<b>Rainfall (mm)</b>	<b>Rainfall ('000 L)</b>	<b>Irri. water + rainfall (mm)</b>	<b>Irri. water + rainfall ('000 L)</b>	<b>Irri. water footprint (mm)</b>	<b>Total water footprint Irri. + rainfall (mm)</b>
<b>Date of sowing</b>									
10 <sup>th</sup> Nov.	12450	300	3000	332	3320	632	6320	241	508
10 <sup>th</sup> Dec.	11196	300	3000	313	3130	613	6130	268	547
10 <sup>th</sup> Jan.	10664	300	3000	219	2190	519	5190	281	487
<b>Different Irrigations</b>									
Limited irrigation (two)	10345	120	1200	288	2880	408	4080	116	394
Limited irrigation (three)	10961	180	1800	288	2880	468	4680	164	427
Penman Monteith at 60% AWC (four)	12099	240	2400	288	2880	528	5280	198	436
Penman Monteith at 50% AWC (five)	12344	300	3000	288	2880	588	5880	243	476

## **4.7 Agro meteorological indices**

### **4.7.1 Growing degree days (GDD)**

The data presented in Table 4.17 depicts the growing degree days for different phenological stages of the potato crop sown under Natural farming conditions. The GDD decreased with delay in sowing and with the increase in frequency of irrigations. Due to change in weather conditions there were some fluctuations in the values. The maximum value for GDD at harvest was 1724, 1529 and 1496 under Limited irrigations (two) for 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sowings, respectively. In case of Limited irrigations (three) the values were 1710, 1510 and 1469 for the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> date of sowing. In case of irrigation scheduling based on different weather models, the GDD were 1654, 1492 and 1450 and 1618, 1444 and 1431 under Penman monteith weather model at 60 % AWC (four) and Penman monteith weather model at 50 % AWC (five) for 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> date of sowing, respectively. These finding are in conformity with Sanjeev (2018).

### **4.7.2 Helio thermal units (HTU)**

Table 4.18 provides the values of helio thermal units for different dates of sowing and irrigation regimes. The maximum value for HTU at harvest was observed under Limited irrigations (two) viz., 14298, 12500 and 12382 for 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sowings, respectively. The HTU decreased with delay in sowing and with the increase in number of irrigations.

### **4.7.3 Photo thermal units (PTU)**

A close view of the data in the Table 4.19 revealed that the highest value for PTU at harvest was seen under Limited irrigation (three) for 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sowing with the values of 21154, 19428 and 19583, respectively. The same trend as GDD and HTU was seen in PTU also.

### **4.7.4 Pheno thermal index (PTI)**

The pheno thermal index for different sowing dates and irrigation regimes is given in Table 4.20. The study of the table revealed that the PTI at harvest for 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> date of sowing was maximum under Limited irrigation (two) treatment. The values being 18.3, 19.18 and 19.27, respectively. The PTI decreased with delay in sowing and with the increase in number of irrigations.

**Table 4.17 Effect of sowing windows and irrigation regimes on GDD**

Phenological stage	Limited irrigation (two)			Limited irrigation (three)			Penman monteith at 60% AWC (four)			Penman monteith at 50% AWC (five)		
	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.
<b>Complete emergence</b>	306	170	96	304	169	94	304	169	92	300	170	92
<b>Vegetative growth</b>	420	250	213	417	245	211	415	243	204	412	241	199
<b>Tuber initiation</b>	506	314	283	501	313	277	495	294	269	488	288	271
<b>Tuber bulking</b>	1127	1136	1048	1122	1077	1040	1089	986	1011	1055	947	986
<b>Harvest</b>	1724	1529	1496	1710	1510	1469	1654	1492	1450	1618	1444	1431

**Table 4.18 Effect of sowing windows and irrigation regimes on HTU**

<b>Phenological stage</b>	<b>Limited irrigation (two)</b>			<b>Limited irrigation (three)</b>			<b>Penman monteith at 60% AWC (four)</b>			<b>Penman monteith at 50% AWC (five)</b>		
	<b>Days taken to</b>	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.
<b>Complete emergence</b>	2465	1001	576	2452	994	560	2431	986	545	2424	976	545
<b>Vegetative growth</b>	3099	1464	1612	3095	1420	1585	3095	1403	1534	3090	1383	1480
<b>Tuber initiation</b>	3511	1953	235	3477	1958	1977	3458	1790	1939	3447	1741	1961
<b>Tuber bulking</b>	9052	9379	9161	8445	9332	9071	7562	9059	8833	7174	8803	8595
<b>Harvest</b>	14298	12500	12382	14214	12404	12262	13832	12304	12079	13776	12036	12012

**Table 4.19 Effect of sowing windows and irrigation regimes on PTU**

Phenological stage	Limited irrigation (two)			Limited irrigation (three)			Penman monteith at 60% AWC (four)			Penman monteith at 50% AWC (five)		
	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.
<b>Complete emergence</b>	3097	1731	1015	3056	1732	994	3078	1723	976	3043	1723	954
<b>Vegetative growth</b>	4264	2587	2355	4235	2529	2322	4213	2507	2256	4180	2481	2190
<b>Tuber initiation</b>	5170	3289	3202	5114	3287	3123	5049	3071	3016	4978	3002	3048
<b>Tuber bulking</b>	13156	13916	13402	12337	13836	13364	11119	13393	12963	10599	12928	12554
<b>Harvest</b>	21154	19428	19583	20961	19169	19482	20186	18920	18686	20090	18924	18686

**Table 4.20 Effect of sowing windows and irrigation regimes on PTI**

Phenological stage	Limited irrigation (two)			Limited irrigation (three)			Penman monteith at 60% AWC (four)			Penman monteith at 50% AWC (five)		
	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.
<b>Complete emergence</b>	8.27	5.24	4.21	8.22	5.36	4.18	8.20	5.31	4.23	8.33	5.41	4.38
<b>Vegetative growth</b>	5.38	4.28	5.63	5.40	4.12	5.64	5.15	4.22	6.11	5.14	4.19	5.88
<b>Tuber initiation</b>	4.82	4.67	9.74	4.93	4.36	7.71	5.11	4.39	6.18	4.84	4.71	6.47
<b>Tuber bulking</b>	7.43	13.41	16.46	7.19	14.92	16.28	7.21	12.74	16.11	7.38	12.47	16.25

#### 4.7.5 Heat use efficiency (HUE)

A perusal of the data presented in the Table 4.21 revealed that the HUE increased with the dates of sowing and decreased with the increase in the frequency of irrigations. The maximum HUE at harvest was observed under Limited irrigations (two) treatment with values 0.63, 0.67 and 0.70 for 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sowing, respectively.

**Table 4.21 Effect of sowing windows and irrigation regimes on HUE**

Phenological stage	Limited irrigation (two)			Limited irrigation (three)			Penman monteith at 60% AWC (four)			Penman monteith at 50% AWC (five)		
	10 Nov	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.	10 Nov.	10 Dec.	10 Jan.
Days taken to												
Tuber initiation	0.47	0.50	0.55	0.46	0.50	0.54	0.43	0.49	0.52	0.42	0.49	0.51
Harvest	0.63	0.67	0.70	0.62	0.66	0.69	0.62	0.65	0.67	0.61	0.64	0.66

#### 4.8 Correlation and Regression studies

##### 4.8.1 Correlation studies

The correlation studies were carried out to see how the dry matter was correlated with the different weather parameters and irrigation for different dates of sowing. A close view of the data in Table 4.22 revealed that in case of 10<sup>th</sup> November sown crop irrigation was positively correlated with dry matter and all weather parameters except rainfall and ET were negatively correlated. For 10<sup>th</sup> December and 10<sup>th</sup> January sowings irrigation and all weather parameters except RH were positively correlated with dry matter.

**Table 4.22 Correlation studies of dry matter with weather parameters and irrigation.**

Dry matter	Weather parameters	Correlation coefficient		
		10 <sup>th</sup> November, 2021	10 <sup>th</sup> December, 2021	10 <sup>th</sup> January, 2022
Dry matter	Rainfall	0.9539	0.8114	0.8076
Dry matter	Irrigation	0.9433	0.9602	0.9585
Dry matter	Max. Temp.	-0.335	0.7715	0.9925
Dry matter	Mini. Temp.	-0.11	0.7238	0.9912
Dry matter	ET	0.736	0.8096	0.9692
Dry matter	RH	-0.088	-0.7681	-0.9879
Dry matter	BSS	-0.588	0.8176	0.9466

#### 4.8.2 Regression and Principal component analysis

The regression and principal component analysis were done for the predictive model to see predictions of the dry matter accumulation. Different regression equations were formed and coefficient of determination ( $R^2$  and adjusted  $R^2$ ) was calculated from the regression model to see the predictions. The principal component is the linear combination of the weather parameters. The PCA gave us the variation in percentage between the observed and predicted values of the dry matter accumulation and it also tells about the contributions of different factors in the biomass studies. The scree plot is the graph between the Eigenvalue and the principal component number. The Eigenvalue is the variances of the principal components. The graph 4.4 shows the observed and predicted values of the dry matter accumulation for the crop growth period. In the initial stages the observed dry matter was more as compared to predicted dry matter. The observed dry matter in the mid stages was less in comparison to the predicted dry matter. Whereas during the final stages of crop growth the observed dry matter increased with respect to predicted dry matter.

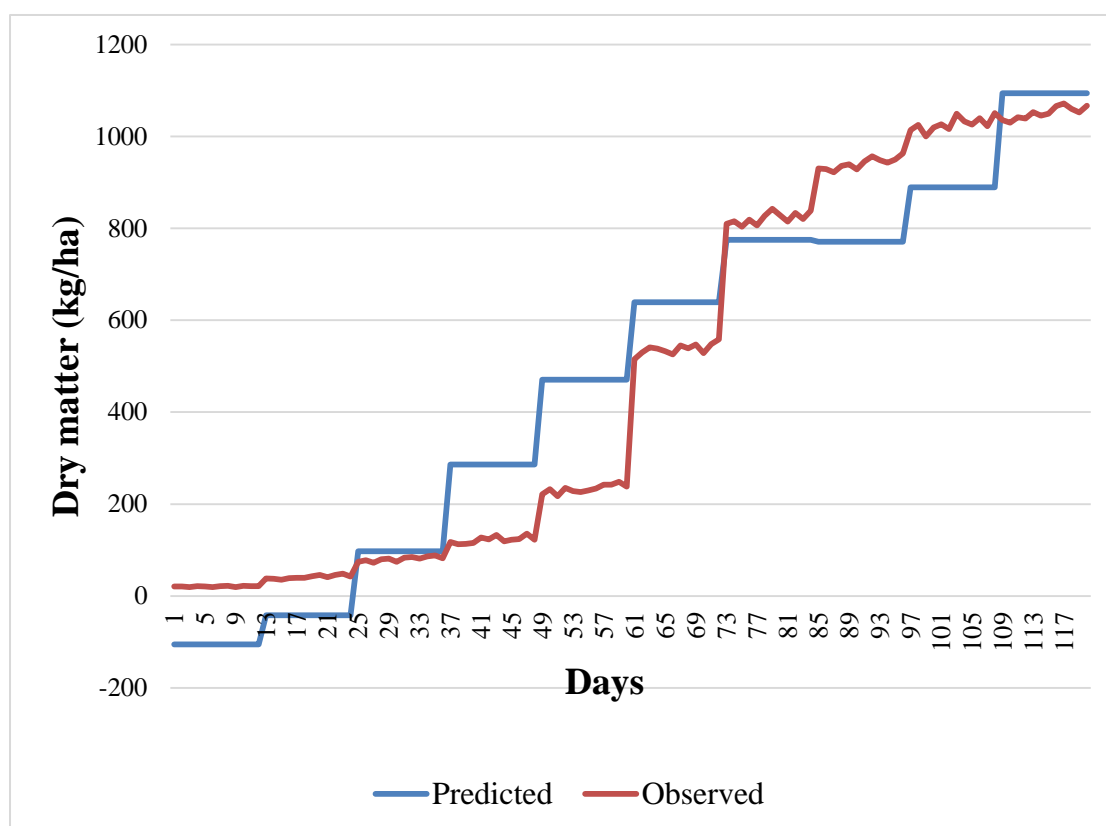
$$\begin{aligned} \text{The regression equation used was } Y &= a_0 + p_1a_1 + p_2a_2 \\ &= 487.524 + p_1*(-70.345) + p_2 * 212.068 \end{aligned}$$

In this the Y is the predicted value a = slope and p stands for principal component.

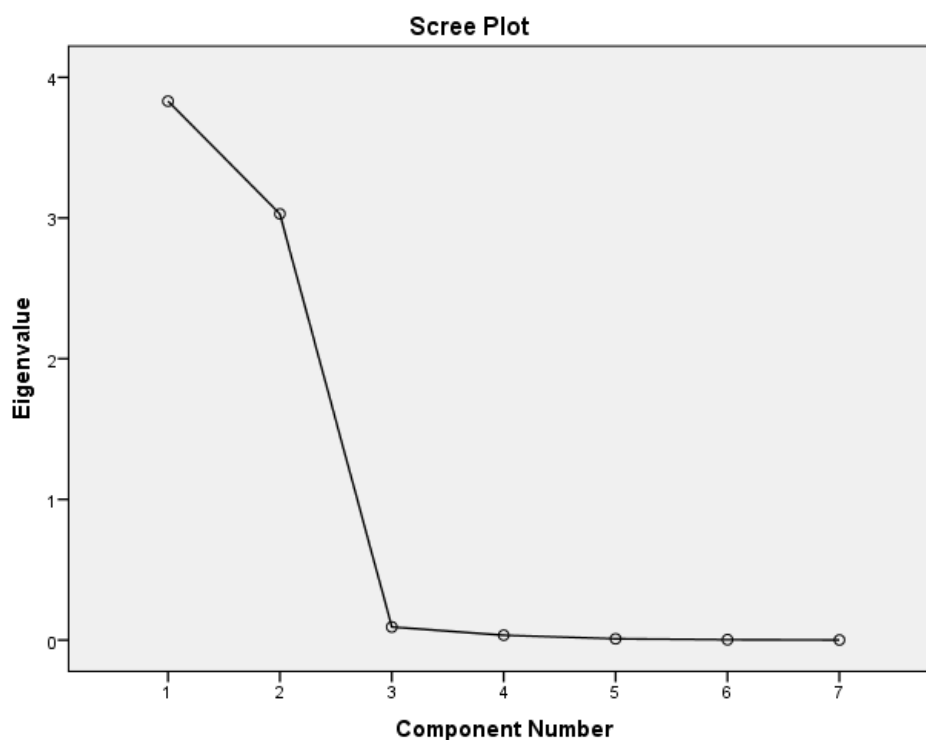
From the regression model the  $R^2$  value we got was 0.901 and the adjusted  $R^2$  value was 0.899. The PCA study showed a variation of 97.996% to the dry matter by the two principal components. The two principal components were taken because after that the scree plot (graph 4.5) had gone asymptotic which showed that there was not much variation after those values. The following equations were used to calculate the different principal components for the first date of sowing:

$$\text{PCA1} = -0.217 * \text{Rainfall} + (-0.1) * \text{Irrigation} + 0.5079 * \text{Max\_Temp} + 0.4886 * \text{Min\_Temp} + 0.1492 * \text{ET} + (-0.455) * \text{RH} + 0.4659 * \text{BSS}$$

$$\text{PCA2} = 0.5153 * \text{Rainfall} + 0.5551 * \text{Irrigation} + (-0.005) * \text{Max\_Temp} + 0.1417 * \text{Min\_Temp} + 0.5466 * \text{ET} + (-0.244) * \text{RH} + (-0.207) * \text{BSS}$$



**Fig. 4.4** Observed and predicted values of dry matter for 10<sup>th</sup> November sown crop



**Fig. 4.5 Scree plot for 10<sup>th</sup> November, 2021**

In the similar way the regression and PCA studies were conducted for the 10<sup>th</sup> December sowing and the graph 4.6 showed that in the initial stages the observed dry matter was more as compared to predicted dry matter. The observed dry matter in the mid stages was less in comparison to the predicted dry matter. Whereas during the final stages of crop growth the observed dry matter increased with respect to predicted dry matter.

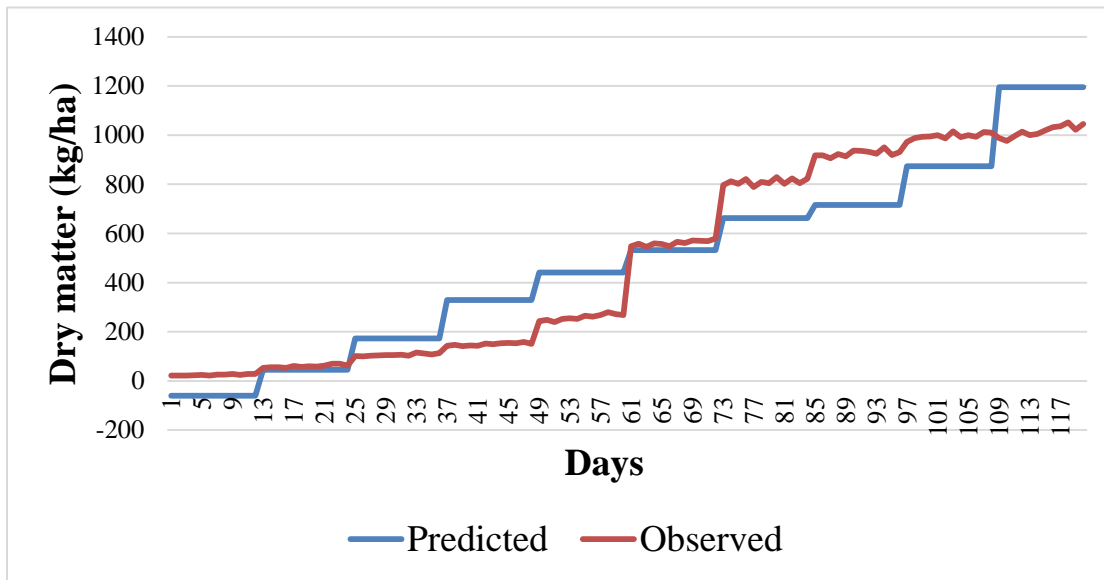
The regression equation used was  $Y = a_0 + p_1a_1 + p_2a_2$

$$= 490.589 + p_1 * 134.890 + p_2 * 153.586$$

From the regression model the  $R^2$  value we got was 0.876 and the adjusted  $R^2$  value was 0.874. The PCA study showed a variation of 97.99% to the dry matter by the two principal components. The two principal components were taken as after these values the scree plot (graph 4.7) had gone asymptotic which showed that there was not much variation after the given values. The following equations were used to calculate the different principal components for the second date of sowing:

$$\text{PCA1} = 0.2308 * \text{Rainfall} + 0.3239 * \text{Irrigation} + 0.4099 * \text{Max\_Temp} + 0.4182 * \text{Min\_Temp} + 0.4036 * \text{ET} + (-0.4368) * \text{RH} + 0.3881 * \text{BSS}$$

$$\text{PCA2} = 0.6359 * \text{Rainfall} + 0.4987 * \text{Irrigation} + (-0.295) * \text{Max\_Temp} + (-0.251) * \text{Min\_Temp} + 0.2592 * \text{ET} + 0.1375 * \text{RH} + (-0.332) * \text{BSS}$$



**Fig 4.6** The observed and predicted values of dry matter for 10<sup>th</sup> December sown crop



**Fig 4.7** The scree plot for 10<sup>th</sup> December, 2021

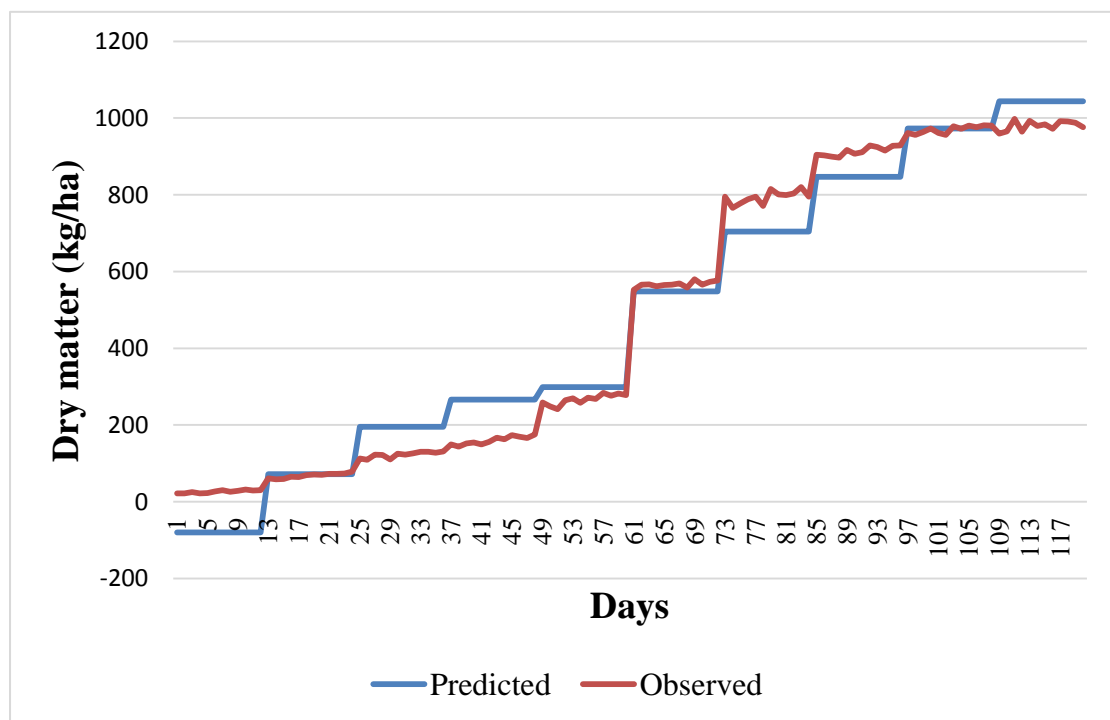
In case of 10<sup>th</sup> January sown crop the regression studies (graph 4.8) showed that in the initial stages the observed dry matter was more as compared to predicted dry matter. The observed dry matter in the mid stages was less in comparison to the predicted dry matter. Whereas during the final stages of crop growth the observed dry matter increased with respect to predicted dry matter.

The regression equation used was  $Y = a_0 + p_1 a_1$

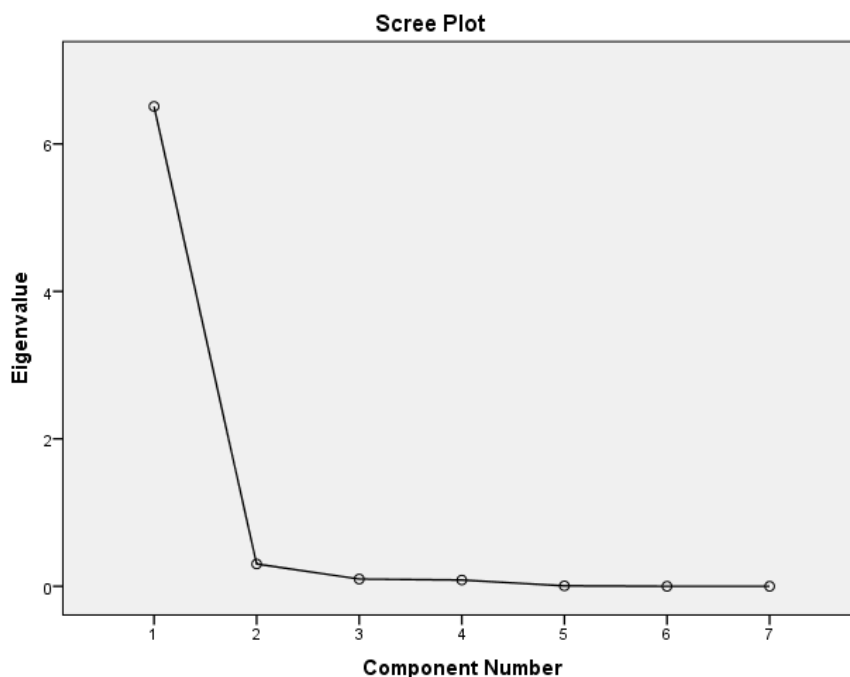
$$= 486.705 + p_1 * 146.131$$

The values from the regression model for  $R^2$  was 0.967 and for adjusted  $R^2$  value was 0.967. The PCA study showed a variation of 92.99% to the dry matter by one principal component. In this case only one principal component was taken as after that the said values in the scree plot (graph 4.9) had gone asymptotic which showed that there was not much variation. The following equations were used to calculate the different principal components for the second date of sowing:

$$\text{PCA1} = 0.3397 * \text{Rainfall} + 0.3749 * \text{Irrigation} + 0.3893 * \text{Max\_Temp} + 0.387 * \text{Min\_Temp} + 0.3841 * \text{ET} + (-0.389) * \text{RH} + 0.3795 * \text{BSS}$$



**Fig 4.8 The observed and predicted values of dry matter for 10<sup>th</sup> January sowing.**



**Fig 4.9 The scree plot for 10<sup>th</sup> January, 2022**

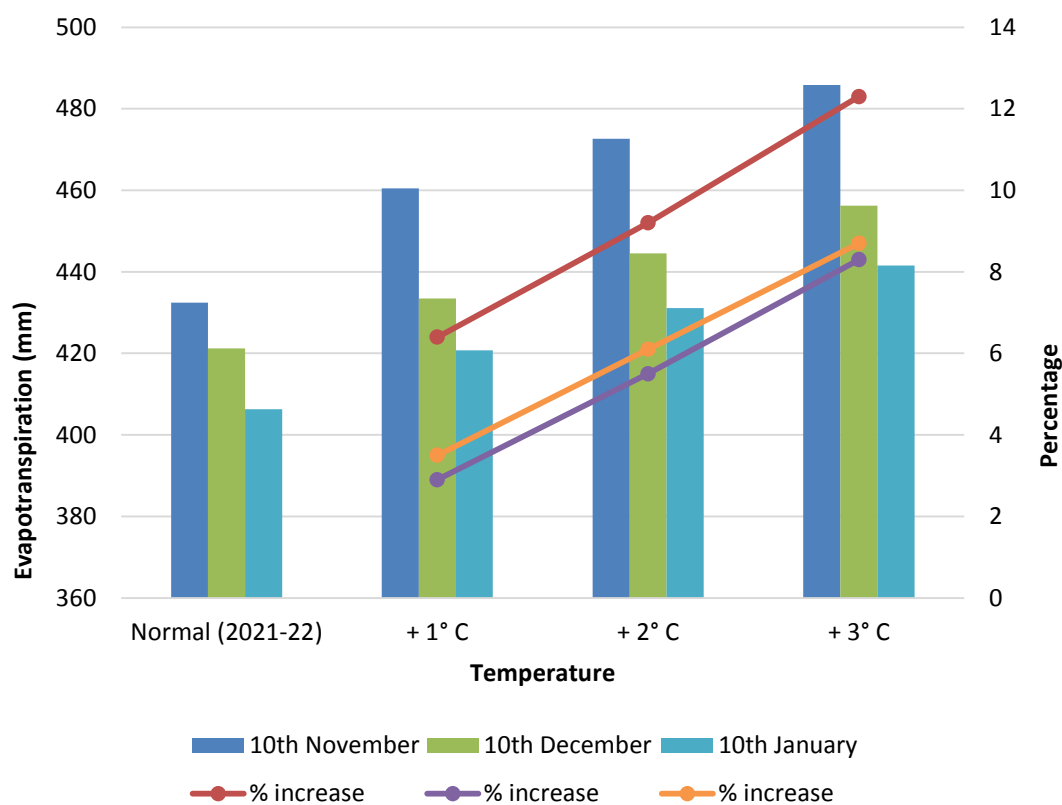
#### **4.9. Impact of elevated temperature +1°, +2° and +3° C on ET<sub>o</sub> (mm) and ET<sub>c</sub> (mm) from the CROPWAT model**

The validation of FAO – CROPWAT model was carried out to investigate the impact of rise in temperature on crop water requirement of potato crop sown under Natural Farming conditions in sub-temperate climate of Himachal Pradesh. Table 4.23 & Fig. 4.10 provides information regarding the effect of elevated temperature on overall and percentage increase in ET<sub>o</sub>. In case of crop sown on 10<sup>th</sup> November the ET<sub>o</sub> calculated by CROPWAT model was 432.45 mm while with increase in temperature by 1°, 2° and 3°C it increased to 460.45 mm, 472.63 mm and 485.81 mm, respectively. The increases were 6.4%, 9.2%, and 12.3% in terms of percentage. For 10<sup>th</sup> December sowing the ET<sub>o</sub> computed by CROPWAT was 421.5 mm and with elevation in temperature it came out to be 433.48 mm, 444.53 mm and 456.24 for 1°, 2° and 3°C, respectively. The increases in terms of percentage were 2.9%, 5.5% and 8.3%. The ET<sub>o</sub> estimated by CROPWAT was 406.29 mm for 10<sup>th</sup> January sown crop whereas with rise in temperature by 1°, 2° and 3°C the ET<sub>o</sub> observed was 420.75 mm, 431.1 mm and 441.54 mm, respectively. The percentage increase from normal was 3.5%, 6.1% and 8.7%.

In the same way the overall and percentage increase in  $ET_c$  was calculated with the rise in temperature by  $1^\circ$ ,  $2^\circ$  and  $3^\circ\text{C}$ . The data presented in Table 4.24 and Fig. 4.11 clearly depicts that the  $ET_c$  calculated for the crop sown on 10<sup>th</sup> November by CROPWAT was 398.12 mm which may increase to 414.04 mm, 424.75 mm and 437.16 mm with  $1^\circ$ ,  $2^\circ$  and  $3^\circ\text{C}$ , respectively. The percentage increase was 4.03%, 6.72% and 9.84%. For 10<sup>th</sup> December sowing the  $ET_c$  calculated by CROPWAT was 385.11 mm and the rise in temperature by  $1^\circ$ ,  $2^\circ$  and  $3^\circ\text{C}$  gave the values of  $ET_c$  as 399.36 mm, 409.37 mm and 433.11 mm, respectively. The increases were 3.7%, 6.3% and 9.3% in terms of percentage. The  $ET_c$  computed from CROPWAT model for 3<sup>rd</sup> sowing was 356.26 mm and with rise in temperature by  $1^\circ$ ,  $2^\circ$  and  $3^\circ\text{C}$  it was observed to be 370.41 mm, 379.32 mm and 385.75 mm, respectively. The increases in terms of percentage were 3.9%, 6.5% and 8.3%. According to a study by Chowdhary et al. (2016) there was an increase in  $ET_c$  with the futuristic elevated temperature scenario. Similar findings reported by Chattarajee et al. (2014) showed that the  $ET_c$  increased with rise in temperature.

**Table 4.23** Impact of elevated temperature  $+1^\circ$ ,  $+2^\circ$  and  $+3^\circ\text{C}$  on  $ET_o$  (mm) from CROPWAT model

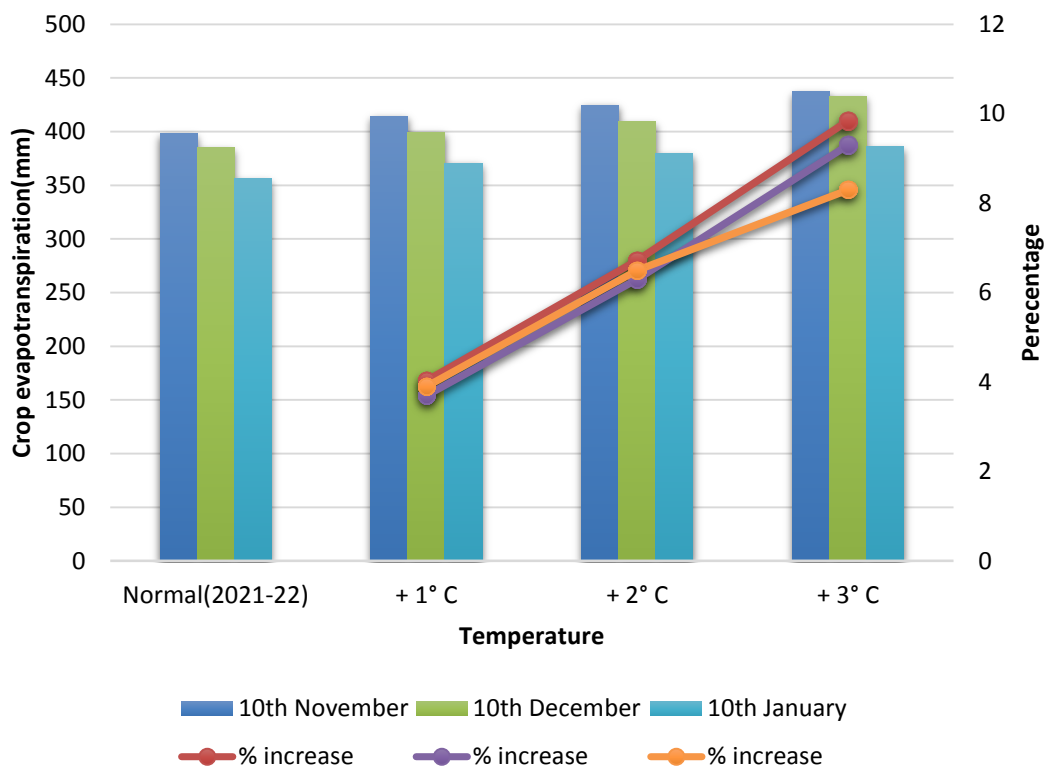
Month	Normal	+ $1^\circ\text{C}$	+ $2^\circ\text{C}$	+ $3^\circ\text{C}$
<b>10<sup>th</sup> November</b>	432.45	460.45	472.63	485.81
% increase		6.4	9.2	12.3
<b>10<sup>th</sup> December</b>	421.25	433.48	444.53	456.24
% increase		2.9	5.5	8.3
<b>10<sup>th</sup> January</b>	406.29	420.75	431.1	441.54
% increase		3.5	6.1	8.7



**Fig. 4.10** Impact of elevated temperature +1°, +2° and +3° C on ET<sub>0</sub> (mm)

**Table 4.24** Impact of elevated temperature +1°, +2° and +3° C on present and futuristic crop water requirement (ET<sub>c</sub>) (mm) from the CROPWAT model.

Month	Normal	+ 1° C	+ 2° C	+ 3° C
<b>10<sup>th</sup> November</b>	398.12	414.04	424.75	437.16
% increase		4.03	6.72	9.84
<b>10<sup>th</sup> December</b>	385.11	399.36	409.37	433.11
% increase		3.7	6.3	9.3
<b>10<sup>th</sup> January</b>	356.26	370.4	379.3	385.75
% increase		3.9	6.5	8.3



**Fig. 4.11 Impact of elevated temperature +1°, +2° and +3° C on crop water requirement ( $ET_c$ ) (mm)**

#### **4.10 Impact of elevated temperature (+1, +2 and +3 °C) and 10 and 20% change in rainfall on present and futuristic irrigation water requirement of potato from CROPWAT model.**

The data given in the Table 4.25 shows that present irrigation water requirement of 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January sown crop was 309.6, 297.8 and 298.2 mm during 2021-22, respectively. Under changed climatic scenario like 1° to 3°C rise in temperature, 1° to 3°C rise in with 10% rainfall deficit, 1° to 3° C rise in temperature with 20% rainfall deficit in future, and 1° to 3°C rise in temperature with 10% rainfall surplus and 1° to 3°C rise temperature with 20% rainfall surplus, the future crop water requirements are projected to rise by approximately 3.62, 6.46 , 9.37% and 4.68, 7.53, 10.43% (10% deficit), 5.68, 8.53, 11.43% (20% deficit), and 2.58, 5.46, 8.33% (10% surplus), 1.61, 4.46, 7.36% (20% surplus) for increase rainfall scenario for 10<sup>th</sup> November sowing, respectively. The corresponding increase in futuristic crop water requirement for 10<sup>th</sup> December sown crop was 3.63, 6.35, 9.10% and 4.73, 7.45, 10.21% (10 % deficit), 5.78, 8.49, 11.22% (20 % deficit) and 2.55, 5.27, 8.03 % (10 % surplus), 1.54, 4.26, 6.99% (20 % surplus), respectively

**Table 4.25 Impact of elevated temperature (+1, +2 and +3 °C) and 10 and 20% change in rainfall on present and futuristic irrigation water requirement of potato from CROPWAT model.**

<b>Date of sowing</b>	<b>Normal</b>	<b>1 °C</b>	<b>2 °C</b>	<b>3 °C</b>	<b>+1 °C &amp; 10%↓</b>	<b>+2 °C &amp; 10%↓</b>	<b>+3 °C &amp; 10%↓</b>	<b>+1 °C &amp; 20%↓</b>	<b>+2 °C &amp; 20%↓</b>	<b>+3 °C &amp; 20%↓</b>	<b>+1 °C &amp; 10%↑</b>	<b>+2 °C &amp; 10%↑</b>	<b>+3 °C &amp; 10%↑</b>	<b>+1 °C &amp; 20%↑</b>	<b>+2 °C &amp; 20%↑</b>	<b>+3 °C &amp; 20%↑</b>
<b>10<sup>th</sup> November, 2021</b>	309.6	320.8	329.7	338.6	324.1	332.9	341.9	327.2	336.0	345.0	317.6	326.5	335.4	314.6	323.4	332.4
<b>Percentage change in CWR (%)</b>		3.62	6.46	9.37	4.68	7.53	10.43	5.68	8.53	11.43	2.58	5.46	8.33	1.61	4.46	7.36
<b>10<sup>th</sup> December, 2021</b>	297.8	308.6	316.7	324.9	311.9	320.0	328.2	315.0	323.1	331.2	305.4	313.5	321.7	302.4	310.5	318.6
<b>Percentage change in CWR (%)</b>		3.63	6.35	9.10	4.73	7.45	10.21	5.78	8.49	11.22	2.55	5.27	8.03	1.54	4.26	6.99
<b>10<sup>th</sup> January, 2021</b>	298.2	308.9	316.8	324.6	311.7	319.5	328.0	316.5	325.1	333.7	306.2	314.0	321.9	303.5	311.4	319.2
<b>Percentage change in CWR (%)</b>		3.59	6.23	8.86	4.57	7.19	9.83	5.50	8.13	10.76	2.77	5.33	7.93	2.01	4.57	7.17

and 3.59, 6.23, 8.86% and 4.57, 7.19, 9.83% (10% deficit), 5.50, 8.13, 10.76% (20% deficit), and 2.77, 5.33, 7.93% (10% surplus), 2.01, 4.57, 7.17% (20% surplus), for 10<sup>th</sup> January sown crop, respectively. Similar results reported by Pareek et al. (2022) showed that with rise in temperature by 3°C and 20% decrease in rainfall resulted in significant increase in the irrigation water requirement.

#### **4.11 Economic studies:**

##### **4.11.1 Cost of production**

Under irrigation scheduling methods based on different weather models the cost of production was found to be highest for Penman monteith weather model at 50 % AWC (five) (INR 115975.00) whereas for the Penman monteith weather model at 60 % AWC (four), Limited irrigation (three) and Limited irrigations (two) it was INR 115375, INR 114775 and INR 114175, respectively. It was similar for all dates of sowing since the inputs used were the same for all treatments.

##### **4.11.2 Gross and net returns**

A close view of the Table 4.26 clearly indicates that the maximum (INR 311260) gross returns were in case of 10<sup>th</sup> November sown crop and under irrigation scheduling based on different weather models it was highest (INR 308588) for Penman monteith weather model at 50% AWC (five). The higher gross returns were due to the higher yields in these treatments. Similarly, the net returns were highest for 10<sup>th</sup> November sowing which was INR 196185 and under irrigation scheduling based on different weather models, Penman monteith weather model at 50 % AWC (five) gave the highest net returns (INR 192613).

##### **4.11.3 B:C**

A cursory glance of the data in Table 4.27 reveals that for different dates of sowing the B:C was maximum (2.11) in case of the crop sown on 10<sup>th</sup> November and for 10<sup>th</sup> December and 10<sup>th</sup> January sowings the ratio was 1.43 and 1.32, respectively. Under irrigation scheduling based on different weather models B:C was maximum for Penman monteith weather model at 50 % AWC (five) with the value of 1.66 whereas it was 1.62, 1.39 and 1.27 for Penman monteith weather model at 60 % AWC (four), Limited irrigation (three) and Limited irrigation (two), respectively.

**Table 4.26 Effect of different treatments on economics of potato (INR ha<sup>-1</sup>)**

<b>Treatment</b>	<b>Gross Returns (INR)</b>	<b>Net Returns (INR)</b>	<b>B:C</b>
<b>Date of sowing</b>			
10 <sup>th</sup> November	311260	196185	1.70
10 <sup>th</sup> December	279910	164835	1.43
10 <sup>th</sup> January	266597	151522	1.32
SE(m)±	2746.42	2746.42	0.02
LSD (P=0.05)	8055.5	8055.5	0.1
<b>Irrigation scheduling based on ET Method</b>			
Limited irrigation (two)	258616	144441	1.27
Limited irrigation (three)	274022	159247	1.39
Penman Monteith at 60% AWC (four)	302463	187088	1.62
Penman Monteith at 50% AWC (five)	308588	192613	1.66
SE(m)±	3171.29	3171.29	0.03
LSD (P=0.05)	9301.6	9301.6	0.1

## 5. SUMMARY AND CONCLUSIONS

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The field experiment entitled, “Simulating crop water requirement of potato under Natural Farming environment in North-Western Himalaya” was conducted during *Rabi* season of 2021-22 at Zero budget natural farm under the Department of Organic agriculture and Natural farming, CSK HPKV, Palampur with the following objectives:

1. To work out the crop water requirement schedules based on different weather models, and
2. to estimate futuristic crop water requirement under limited irrigations using validated FAO-CROPWAT Model under Natural farming conditions.

In this experiment twelve treatments were laid out in randomized block design with three replications. The meteorological data during the crop season have been illustrated graphically in Fig. 3.1. The important findings emerged from the present study have been summarized in this chapter as under:

1. The phenological parameters viz. plant height, root length, number of plants per metre sq., number of leaves per plant and LAI were observed to be statistically higher in 10<sup>th</sup> November sown crop. The days to tuber bulking and days to harvest were significantly higher for 10<sup>th</sup> November sown crop and were lowest in case of 10<sup>th</sup> January sown crop. Amongst irrigation scheduling, the phenological parameters were significantly higher for Penman monteith weather model at 50% AWC (five) which were at par with Penman monteith weather model at 60% AWC (four). In case of 10<sup>th</sup> November sown crop with irrigation scheduling based on Penman monteith weather model at 50% AWC (five), the number of plants per metre sq., plant height, number of leaves per plant and LAI were observed to be the highest.
2. The number of shoots per plant were highest for 10<sup>th</sup> November sown crop with irrigation scheduling based on Penman monteith weather model at 50% AWC (five). The average number of tubers and average tuber weight were

- significantly higher for 10<sup>th</sup> November sown crop. Amongst irrigation scheduling the average number of tubers and average tuber weight were observed to be highest under Penman monteith weather model at 50% AWC (five) which was significantly at par with Penman monteith weather model at 60% AWC (four).
3. The maximum yield (125.5q/ha) observed for 10<sup>th</sup> November sowing which was 12.15 and 21.72% higher than 10<sup>th</sup> December and 10<sup>th</sup> January sowing, respectively. The significantly higher yield to the tune of 123.4 q/ha obtained under under irrigation scheduling based on Penman monteith weather model at 50% AWC (five) treatment which was significantly at par with Penman monteith weather model at 60% AWC (four) (120.9 q/ha). The yield obtained with Penman monteith weather model at 50% AWC (five) was 2.07, 12.59 and 23.15% higher than irrigation scheduling based on Penman monteith weather model at 60% AWC (four), limited irrigation(three) and limited irrigation(two), respectively.
  4. The economic studies revealed that the maximum profit was obtained in 10<sup>th</sup> November sown crop and under irrigation scheduling, maximum profit was under Penman monteith weather model at 50% AWC (five) with B:C ratio of 1.70 and 1.66, respectively.
  5. In crop water requirements studies the actual evapotranspiration (AET) was estimated from soil water balance method and was validated with ET values estimated from the FAO-CROPWAT model which showed a variation of 12.87%, 12.18% and 12.47% when crop sown at 10<sup>th</sup> November, 10<sup>th</sup> December and 10<sup>th</sup> January, respectively.
  6. The climatic grids of +1° C, +2° C, +3° C elevated temperature regimes were used to estimate ET<sub>crop</sub> using FAO-CROPWAT model. The results indicated that the ET<sub>crop</sub> increased by 4.0, 6.7 and 9.8% with +1° C, +2° C, +3° C rise respectively in 1<sup>st</sup> date of sowing and 3.7, 6.3 and 9.3% at 2<sup>nd</sup> and 3.9, 6.5 and 8.3% for 3<sup>rd</sup> date of sowing, respectively.
  7. Under climate grids of +1<sup>0</sup> , +2<sup>0</sup> and +3<sup>0</sup> C elevated temperature regimes, the increase in net irrigation water requirement was between 4.57-10.43% and

2.58-8.33% with 10% decrease and 10 % increase in rainfall, respectively, whereas it ranged between 5.50-11.43% and 1.54-7.36% for rainfall deficit of 20% and surplus of 20%, respectively.

8. The correlation studies showed that for 1<sup>st</sup> date of sowing rainfall, irrigation and ET were positively correlated whereas others were negatively correlated. For 2<sup>nd</sup> and 3<sup>rd</sup> dates of sowing irrigation and all the weather parameters except RH showed positive correlation with dry matter.
9. The regression and principal component analysis studies indicated that there was 97.99, 95.18 and 92.99% variation in the dry matter for 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> date of sowing which was explained by the standardized parameters of the model. The PCA concluded that the rainfall and irrigation were the major contributing factors for the yield.
10. The irrigation water footprints were 241 for 1<sup>st</sup> date of sowing, 268 for 2<sup>nd</sup> date of sowing and 281 for 3<sup>rd</sup> date of sowing and under irrigation scheduling, it was observed that the water footprints were 116, 164, 198 and 243 under limited irrigation(two), limited irrigation(three), Penman monteith weather model at 60% AWC (four), Penman monteith weather model at 50% AWC (five).

### **Conclusion:**

1. The study concluded that the irrigation scheduling based on Penman monteith weather model at 60% AWC (four) proved to be the best amongst all the treatments as it gave statistically similar yield compared to the Penman monteith weather model at 50% AWC (five) with less amount of water of the estimated  $ET_0$  by the validated FAO – CROPWAT model. The Penman monteith weather model at 60% AWC (four) schedule using real time weather data emerged as the best option in potato cultivation for saving the 60 mm (6 Lakh litre per ha) water without affecting the yield significantly. The interval of irrigations schedules simulated through CROPWAT and the actual irrigations applied were also not large.

“Potato sown in mid hill sub temperate climate conditions of H.P. gave highest yield when sown during November 10<sup>th</sup> with Penman monteith weather model at 60% AWC (four). The corresponding water footprints were lower in Penman monteith weather model at 60% AWC (four) compared to Penman monteith weather model at 50% AWC (five), hence saving 60 mm (6 Lakh litre per ha) of water” when using the real-time weather data for scheduling of irrigations water”.

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## APPENDICES

**Mean weekly weather data at Palampur during *rabi* 2021-22 (November 2021 to May 2022)**

<b>Standard</b>	<b>Maximum</b>	<b>Minimum</b>	<b>Average</b>	<b>Rainfall</b>	<b>BSS</b>
<b>Week</b>	<b>Temperature</b>	<b>Temperature</b>	<b>RH</b>	<b>(mm)</b>	<b>(hrs)</b>
	<b>(°C)</b>	<b>(°C)</b>	<b>(%)</b>		
46	22.1	8.1	72.6	0.00	9.4
47	20.2	6.2	80.8	0.00	9.3
48	20.6	6.6	82.4	0.00	9.3
49	18.3	7	77	1.4	5.3
50	18.1	6.2	73.7	20.1	6.9
51	15	3	80.3	0.00	6.6
52	16.1	3.4	79	0.00	7.9
1	14.6	3.4	78.9	5.3	6.1
2	14.1	6.7	88.7	108.6	2.9
3	14.1	3.1	80.6	56.2	5.9
4	15.1	5.4	82.6	7.8	4.1
5	10.9	2.1	90.3	75.2	3.9
6	13.3	3.2	83	41.4	5
7	15.8	4.1	72.3	0.00	8.1
8	17.8	4.3	73.1	0.00	9.9
9	18	7	74	29.9	6.8
10	18.3	6	75	16.9	6.2
11	22.3	9.6	65.7	0.00	7.4
12	27.2	14.3	66.6	0.00	9.8
13	28	13.7	46.9	0.00	9.5
14	29	14.8	46.8	0.00	10.3
15	29.6	15.9	44.3	0.00	10.4
16	31.3	16.7	49.4	5.5	8.3
17	29.4	16.5	42.3	11.2	8.1
18	30.9	17.3	40.4	0.00	9.3
19	29.8	17.5	51.4	6.9	5.1
20	29.3	18.3	56.6	46.7	6.3

### Appendix II

#### Fixed cost of potato cultivation (ha<sup>-1</sup>)

S. No	Particulars	Operational input per hectare	Rate (₹)	Units	Total cost (₹ ha <sup>-1</sup> )
1.	Seed	2500kg	28	2500	70000
2.	Ploughing	12 hour	500	12	6000
3.	Labour				
	Plot preparation	8 mandays	300	8	2400
	Sowing	15 mandays	300	15	4500
	Harvesting	18 mandays	300	18	5400
4.	Natural farming practices				24075
	Cost of cultivation				112375

#### Treatment wise variable cost of cultivation (Rs ha<sup>-1</sup>)

Treatments	particulars	quantity	Unit	Rate (Rs ha <sup>-1</sup> )	Amount (Rs ha <sup>-1</sup> )
2 irrigations	Irrigation	2	Per Irrigation	600	1200
	Labour	2	Mandays	300	600
			Total		1800
3 irrigations	Irrigation	3	Per Irrigation	600	1800
	Labour	2	Mandays	300	600
			Total		2400
4 irrigations	Irrigation	4	Per Irrigation	600	2400
	Labour	2	Mandays	300	600
			Total		3000
5 irrigations	Irrigation	5	Per Irrigation	600	3000
	Labour	2	Mandays	300	600
			Total		3600

**Treatment wise cost of cultivation (Rs ha<sup>-1</sup>)**

<b>Treatments</b>	<b>Fixed Cost</b>	<b>Variable Cost</b>	<b>Total cost of cultivation</b>
2 Irrigations	112375	1800	114175
3 Irrigations	112375	2400	114775
4 Irrigations	112375	3000	115375
5 Irrigations	112375	3600	115975

**Appendix III****Analysis of variance for Plant height (cm)**

<b>Source of variation</b>	<b>Degree of freedom</b>	<b>Mean sum of square</b>		
		60 DAS	90 DAS	AT harvest
Replication	2	1.25	0.52	0.27
Treatment	11	8.26	7.92	14.85
Date of sowing (a)	2	98.402	34.71	37.32
Irrigation scheduling (b)	3	19.35	40.26	120.38
Interaction(a*b)	6	2.07	2.38	5.34
Error (ESS)	22	0.883	3.26	10.14
Total sum of Sq	35	24.30	18.61	42.53

### Appendix IV

#### Analysis of variance for growth and development attributes

Source of variation	Degree of freedom	Mean sum of square				
		Days to emergence	Days to vegetative growth	Days to tuber initiation	Days to tuber bulking	Days to maturity
Replication	2	0.19	2.58	1.69	0.69	0.028
Treatment	11	37.34	23.8	52.12	187.62	428.64
Date of sowing (a)	2	639.69	364.33	850.78	3228.9	7429.5
Irrigation scheduling (b)	3	1.21	13.44	17.95	11.30	26.99
Interaction(a*b)	6	0.21	3.33	2.93	3.05	0.49
Error (ESS)	22	1.01	1.77	2.18	2.51	2.69
Total sum of Sq	35	116.76	71.73	161.18	591.81	1358.4

### Appendix V

#### Analysis of variance for no. of plants/m<sup>2</sup> and no. of leaves/ plant

Source of variation	Degree of freedom	Mean sum of square			
		No. of plants/m <sup>2</sup>	No. of leaves/ plant		
			60 DAP	90 DAP	At harvest
Replication	2	0.15	0.32	0.39	1.69
Treatment	11	0.46	0.81	0.99	1.47
Date of sowing (a)	2	0.57	7.96	1.14	4.90
Irrigation scheduling (b)	3	0.19	3.24	7.71	7.93
Interaction(a*b)	6	0.12	0.09	0.34	0.72
Error (ESS)	22	0.60	0.07	0.30	0.47
Total sum of Sq	35	0.22	2.38	2.49	3.45

### Appendix VI

#### Analysis of variance for leaf area index

Source of variation	Degree of freedom	Mean sum of square		
		60 DAP	90 DAP	At harvest
Replication	2	0.01	0.05	0.0002
Treatment	11	0.14	0.09	0.08
Date of sowing (a)	2	1.58	0.32	0.59
Irrigation scheduling (b)	3	0.39	0.61	0.41
Interaction(a*b)	6	0.002	0.04	0.006
Error (ESS)	22	0.03	0.03	0.01
Total sum of Sq	35	0.39	0.25	0.22

### Appendix VII

#### Analysis of variance for yield attributing characters

Source of variation	Degree of freedom	Mean sum of square		
		No. of shoots/plant	Average no. of tubers/plant	Average tuber weight(g)
Replication	2	0.09	0.08	0.45
Treatment	11	0.74	0.14	10.34
Date of sowing (a)	2	0.78	0.30	23.87
Irrigation scheduling (b)	3	7.79	1.01	98.07
Interaction(a*b)	6	0.03	0.01	0.39
Error (ESS)	22	0.04	0.05	0.76
Total sum of Sq	35	2.28	0.34	31.30

### Appendix VIII

#### Analysis of variance for yield and grading ( $\text{q ha}^{-1}$ )

Source of variation	Degree of freedom	Mean sum of square			
		Yield	Grading		
			>75g	50-75g	<50g
Replication	2	7.65	6.12	13.19	8.77
Treatment	11	141.04	11.75	45.71	40.94
Date of sowing (a)	2	1009.5	73.43	153.89	272.81
Irrigation scheduling (b)	3	803.81	49.46	240.98	199.93
Interaction(a*b)	6	37.59	8.67	54.69	6.99
Error (ESS)	22	12.06	2.36	9.75	10.37
Total sum of Sq	35	423.27	31.57	123.53	107.94

### Appendix IX

#### Analysis of variance for shoot dry matter accumulation (kg ha<sup>-1</sup>)

Source of variation	Degree of freedom	Mean sum of square									
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS	110 DAS	At harvest
Replication	2	0.86	2.63	29.90	9.64	32.19	147.31	184.08	9.91	13.12	277.26
Treatment	11	11.69	154.95	336.44	317.63	337.41	260.44	314.01	265.29	695.84	1129.45
Date of sowing (a)	2	80.93	2233.02	5301.14	4515.18	3688.17	2287.41	2288.07	2250.87	9669.09	14935.45
Irrigation scheduling (b)	3	47.98	245.42	236.39	437.47	1137.07	521.55	860.74	952.58	940.67	1644.97
Interaction(a*b)	6	7.41	11.24	5.09	37.38	32.14	23.88	54.59	19.30	11.46	289.71
Error (ESS)	22	2.62	6.74	16.99	24.12	34.75	60.83	142.55	81.36	95.42	110.56
Total sum of Sq	35	31.84	479.07	1031.09	960.64	998.22	680.25	680.53	679.57	2020.82	3322.19

### Brief Biodata of student

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### Academic Qualifications:

Examination Passed	Year of passing	School/College Board/ University	Marks(%) or OGPA
10 <sup>th</sup>	2013	CBSE, New Delhi	79.80
10+2	2015	HPBOSE, Dharamshala	82.20
B.Sc. (Hons.) Agriculture	2020	CSKHPKV, Palampur	7.27/10.0

Fellow/Scholarship/Gold Medals/Awards/Any Other Distinction: Nil

Publications: Nil

Total: Nil

Research papers (in peered journals): Nil

Scientific Popular Articles: Nil