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RESEARCH ARTICLE

Variation of in-situ soil moisture under different irrigation regimes: An Experience under potato production in Meghalaya

D.J. Das[1], Lala I.P. Ray[2*], Emillia[1], J. Das[1], G.P. Mishra[1], A.K. Singh[3], N.J. Singh[3] and S. Swami[4]

Abstract

Under limited availability of water, maximization of water productivity can be possibly achieved with deficit irrigation regimes. A field trial was taken with potatoes as the test crop during the winter season of 2022-23 to study the variation of soil moisture under different irrigation scenarios and crop performance under mid hills of Meghalaya. The experiment was conducted in split plot design with four different levels of irrigation regimes, viz., 45% (M1), 60% (M2), 75% (M3) and 90% (M4) as main plot treatment and three potato varieties, viz., Kufri Jyoti (V1), Kufri Megha (V2) and Kufri Giriraj (V3) under sub plot treatment and replicated thrice. The maximum variation recorded was 18.46, 21.73, 24.73 and 27%, under M1, M2, M3, and M4, respectively. Similarly, the total range of water used varied between 575.3 to 124.8 mm. The highest value of water productivity (75.34 kg ha-1 mm-1) was recorded under M4 irrigation regime. Similarly highest water productivity was recorded for V1 (54.50 kg ha-1 mm-1), over V2 and V3, but was statistically at par with V2 (50.83 kg ha-1 mm-1).

Keywords: Deficit irrigation, Maximum Allowed Depletion, North Eastern Region (NER), Potato variety, Water productivity

Introduction

North-eastern zone of India experiences a relatively higher duration of humid climate, with heavy rainfall during the monsoon and summer months and a dry winter season. Rainfall in the North Eastern states of India is substantial (above the national average) each year (Choudhury *et al.,* 2012; Ray *et al.*, 2012; Dikshit and Dikshit, 2014; Ray *et al.*, 2019). The average annual rainfall of Meghalaya, a state in Northeast India, is more than 2,000 mm, with a range between 14,000 to 740 mm (Ray *et al.*, 2012). Furthermore, Meghalaya's hilly topography creates water deficit scenario during non-rainy seasons due to non-adherence of proper rainwater conservation strategies (Khan *et al.*, 1987; Choudhury *et al.,* 2012; Dey *et al.*, 2017; Marwein and Ray, 2019). Optimising time and amount of water supplied for enhancing yield can be accomplished by creating an efficient irrigation schedule (Dey and Ray, 2017a; Gogoi et al., 2020; Devi *et al.*, 2023).

The performance of potato cultivation, is linked to water availability and management, particularly in regions characterized by unique agro-climatic conditions, such as Northeast India (Dey and Ray, 2017b; Gogoi and Ray, 2019; Das and Ray, 2025). According to Devaux *et al.* (2014) and Scott *et al.* (2000), potatoes (Solanum tuberosum L.) are among the most significant crops in the globe, particularly in Asian and African nations. Third in terms of human consumption after rice and wheat, it ranks fourth globally in terms of production volume, after wheat, rice, and maize (Shock *et al.*, 1998; Scott and Suarez, 2011; Saxena and Mathur, 2013; FAO, 2021; Satya et al., 2023). According to Sah et al. (2011), potato is grown all year round under assured irrigation and rainfed conditions. It has a significant impact on the farming systems and the food of people living in the northeast (Kumar et al., 2006). North East shares almost 10% of the India's total area under potato cultivation and 4% of its total production (Gupta et al., 2004). The NEH region has 18,173 ha land under cultivation, producing 1, 81,089 M t of

[1]M. Sc. (Agronomy) School of Natural Resource Management, College of Postgraduate Studies in Agricultural Sciences, (CAU-Imphal), Umiam-793103, Meghalaya.

[2]Corresponding Author, Professor (Soil and Water Engineering), School of Natural Resource Management, College of Postgraduate Studies in Agricultural Sciences, (CAU- Imphal), Umiam-793103, Meghalaya.

[3,4]Associate Professor and Professor, respectively, School of Natural Resource Management, College of Postgraduate Studies in Agricultural Sciences, (CAU- Imphal), Umiam-793103, Meghalaya.

***Corresponding Author:** Lala I.P. Ray, Corresponding Author, Professor (Soil and Water Engineering), School of Natural Resource Management, College of Postgraduate Studies in Agricultural Sciences, (CAU- Imphal), Umiam-793103, Meghalaya, E-Mail: lalaipray@rediffmail.com

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potatoes (Sadawarti et al., 2013; Saxena and Mathur, 2013; Mawthaoh *et al*., 2019).

It is necessary to consider water supply through deficit irrigation in order to maximise yield and water productivity simultaneously (Shock et al., 1992; Yuan et al., 2003; Bisht et al., 2012). According to Rudnick et al. (2017), deficit irrigation is a water management strategy used in situations where there is not enough water to meet crop evapotranspiration demands without compromising potential yield. One of the key strategies for conserving water by lowering the quantity of irrigation water used is deficit irrigation (Fereres and Soriano, 2007). However, the lack of water compromises yield. Hence, yield reduction due to water shortage must be quantified.

Taking the above considerations, an agronomic field investigation was carried out during winter season (2022-23) at the experimental field of College of Post Graduate Studies in Agricultural Science (CAU, Imphal), Umiam, Meghalaya with dual objectives to study the variation of soil moisture under different irrigation regimes and the total amount of water used for growing potato and to assess the production potential of potato and water productivity.

Materials and Methods

Experimental site and meteorological conditions

A field trial was conducted at the experimental farm of the College of Postgraduate Studies in Agricultural Sciences in the Ri-Bhoi district of Meghalaya during winter season of 2022-2023. The experimental station is located at an elevation of 950 m above Mean Sea Level at longitudes of 91o 18′ to 92o 18′ East and latitudes of 25o 40′ to 26o 20′ North. The details of the experimental site are shown in Fig. 1.

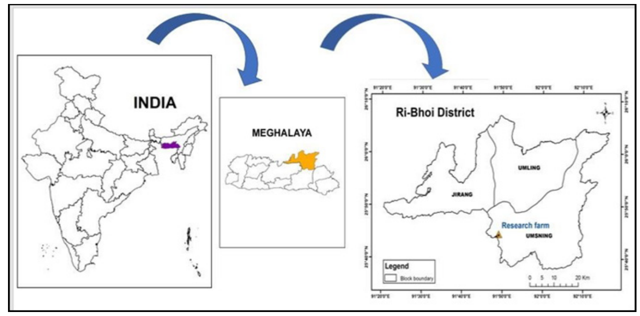

Fig 1: Location map of the experimental site

Ri-Bhoi district of Meghalaya has a subtropical humid climate, meaning it receives a lot of rainfall and experiences cold winters. Rainfall during the monsoon season often begins in the first two weeks of June and continues till the end of September. According to Ray *et al*. (2012), Umiam region of Ri-Bhoi district used to receive 2617.10 mm of average annual rainfall, with a few spells of pre-monsoon showers occurring from March to May. The months of July and August receives the highest temperature of up to 30°C, while the first week of January has the lowest temperature of 5 to 6°C.

A total of 19.3 mm rainfall was received during the experimentation period, with the 47th standard meteorological week (SMW) receiving the highest weekly rainfall of 9.1 mm. The highest recorded weekly maximum temperature, i.e., 26.88°C, occurred during the 49th SMW, while the lowest recorded temperature of 21.29°C, occurred during the 3rd SMW. The 52nd SMW registered highest mean weekly minimum temperature of 26.67°C, while the 47th SMW recorded the lowest (9.17°C). Similarly, the average relative humidity was recorded to be around 72% on weekly basis. The weekly meteorological data are presented in Table 1.

Composite soil samples were collected prior to the conduct of the field experiment randomly at a depth of 0-30 cm. Representative soil samples were analysed to determine the various physico-chemical properties using standard protocols. It was found that the soil type of the trial field was sandy clay loam. The initial pH of the soil is 5.26 and its organic carbon content is 0.88%. At 0-30 cm, the average levels of available potassium (K_2O), phosphorus (P_2O_5), and nitrogen (N) were 274.6, 18.4, and 236.3 kg ha^{-1}, respectively.

Experimental design and treatment combinations

Split plot experimental design was adopted for executing this field trial. Under main plot four treatments of irrigation regimes were taken. Deficit irrigation method was followed to ascertain the Maximum Allowable depletion (MAD). Four moisture regimes (M_1: 45% of MAD, M_2: 60% of MAD, M_3: 75% of MAD, and M_4: 90% of MAD) were put under main plot and three potato varieties (Kufri Jyoti, Kufri Megha, and Kufri Giriraj) were allotted under the sub. The experiment was replicated thrice. Potatoes seed tubers were planted with 50 × 20 cm^2 spacing with 2 t ha^{-1} seed rate, following the recommended fertiliser dosage of 100: 80: 60 kg ha^{-1} (N: P_2O_5: K_2O).

Estimation of soil moisture percentage (%)

Soil sampling for estimation of in-situ soil moisture was done every alternate date using a soil auger and an aluminium box, soil samples were collected from each plot up to a depth of 30 cm. A digital balance was used to determine the weight of the samples. After keeping 24 hours at 105°C in the oven, the soil samples were weighed once more until a steady weight was reached. Soil moisture content was calculated by using the formula presented in Eq. 1.

Soil moisture content (%)

= [weight of water (g)/ weight of oven dry soil (g)] × 100 ..(1)

Quantification of irrigation water

Surface method of irrigation was used during the experiment. To ensure accurate and appropriate irrigation, gravimetric soil moisture content measurements must be prerequisite.

Table 1 : Weekly meteorological data prevailed during crop growing season and the amount of irrigation water applied during the experiment

SMW	*Total Rainfall (mm)*	*Avg. Max. temperature (˚C)*	*Avg. Min. temperature (˚C)*	*Relative Humidity (%)*	*Avg. daily evaporation (mm)*
46	0	28.00	9.93	76.92	2.80
47	9.1	26.57	9.17	72.79	1.73
48	6.0	25.36	14.64	71.68	1.53
49	1.4	26.88	17.5	70.47	1.30
50	1.4	26.67	25.36	68.06	1.40
51	1.4	24.71	26.63	77.13	0.84
52	0	25.13	26.67	69.54	1.08
1	0	24.07	24.14	71.26	1.49
2	0	23.50	23.69	69.89	1.08
3	0	21.29	23.00	70.71	1.2
4	0	22.57	22.43	79.40	1.1
5	0	21.86	20.29	77.04	0.56
6	0	21.57	18.14	74.27	0.3
7	0	22.43	15.86	74.94	0.28
8	0	23.29	18.79	74.29	0.5
9	0	25.07	19.14	57.11	0.29

In order to determine the irrigation scheduling, precisely calculated the irrigation depth and frequency, the impact of varying soil moisture levels on potatoes was studied. Before planting in each treatment, 100 mm of irrigation water was initially applied to bring the soil moisture level nearer to the field capacity for uniformity. This water was considered as application water (ploughing) and was not included in the overall volume of water utilised in the experiment.

The volumetric measurement was used to quantify irrigation water. The furrow method of irrigation was used to deliver irrigation water. A 0.5 HP electric pump was used to quantify the amount of irrigation water applied based on discharge rate. A 200 L bucket was used to record the average discharge of the pump. The time it took to fill the bucket was also recorded, and the water discharge to the respective plots was computed as a result. The discharge rate of the pump was determined volumetrically as presented in Eq. 2. The average discharge rate of pump was recorded as 0.53 lit sec-1.

$$\text{Discharge rate (L sec}^{-1}) = \frac{\text{Amount of water collected in the bucket}}{\text{Time require to fill the bucket}} \ldots (2)$$

Water productivity

The water productivity of crop was calculated as the ratio of tuber yield to total amount of water applied as presented in Eq. 3 and it is expressed in kg ha^{-1} mm^{-1}.

$$\text{Crop water productivity} = \frac{\text{Economic yield}}{\text{Total amount of water applied}} \qquad (3)$$

Sampling, soil moisture monitoring and data analysis

Three (03) randomly chosen plants from each treatment plot were tagged as sample plants, with the exception of the plant located in the border rows. Biometric observations, such as plant height, number of branches per plant, accumulation of dry matter per plant, tuber yield, and biological yield, were noted from these tagged plants. While yield attributes were taken at the time of harvesting. Using the analysis of variance approach for split plot design, the data collected from several investigations during the research were statistically analysed. According to Gomez and Gomez (1984), the difference between the treatment means was tested for statistical significance using an appropriate critical difference (CD) value at the 5% level of significance.

Results and Discussion

Total amount of water applied and irrigation scheduling

The depth of irrigation water applied and the number of irrigations given is presented in Table 2. The depths of irrigation for M_1: 45% of MAD, M_2: 60% of MAD, M_3: 75% of MAD and M_4: 90% of MAD are 69.5, 81.5, 93.5 and 105.5 mm, respectively per irrigation cycle in order to bring the soil moisture nearer to the field capacity level.

The highest total number of irrigations was applied under M_1 treatment amounting to eight (08), however least number of irrigation was given to M_4 treatment.

Soil moisture variation at deficit irrigation regimes

Based on soil moisture depletion, irrigation was applied at 45, 60, 75 and 90% of MAD, considering 0-30 cm as the effective rooting zone depth of potato. During the crop growth period, total number of irrigations in M_1, M_2, M_3, and

Table 2 : Irrigation depths (mm) and frequency of irrigations under different treatments

Duration of crop	M1	M2	M3	M4	Effective Rainfall (mm)
Day 1					
Day 2-11					9.1
Day 12-21	1	1			6
Day 22-31	1				1.4
Day 32-41		1			1.4
Day 42-51	1				1.4
Day 52-61	1				0
Day 62-71	1	1	1		0
Day 72-81	1			1	0
Day 82-91	1				0
Day 92-101	1	1	1		0
Day 102-111					0
Day 112-121					0
Total number of irrigation	8	4	2	1	19.3
Depth of irrigation per cycle (mm)	69.5	81.5	93.5	105.5	
Total amount of water applied (mm) (I+ER)	575.3	345.3	206.3	124.8	

Table 3 : Effect of irrigation regime and potato varieties on yield, yield attributes and water productivity of potato

Treatments	*Number of tubers per plant*	*Weight of tubers per plant (g)*	*Tuber yield (t ha-1)*	*Water productivity (kg ha-1 mm-1)*
	Main plot (Levels of irrigation = 04)			
M1 – 45% of MAD	7.15	222.77	16.04	27.88
M2 – 60% of MAD	6.27	209.19	13.61	39.42
M3 – 75% of MAD	5.10	205.44	11.99	58.13
M4– 90% of MAD	4.34	175.05	9.40	75.34
S.E.(m) ±	0.34	9.22	0.82	2.86
C.D.(p = 0.05)	1.34	36.20	3.24	11.22
	Sub-plot (Level of cultivar = 03)			
V1 – Kufri Jyoti	6.02	191.59	13.73	54.50
V2 – Kufri Megha	6.01	177.48	12.96	50.83
V3 – Kufri Giriraj	5.12	240.26	11.59	45.23
S.E.(m) ±	0.22	6.96	0.55	1.59
C.D.(p = 0.05)	0.66	20.67	1.64	4.72

M_4 are 8, 4, 2, and 1 could be applied, respectively. From the observation, M_1 recorded highest number of irrigation than M_2, M_3 and M_4. The depths of irrigation for M_1, M_2, M_3 and M_4 are 69.5, 81.5, 93.5 and 105.5 mm, respectively per irrigation cycle to bring the soil moisture nearer to the field capacity level (Table 2). Result showed that, M_1 recorded the highest amount of irrigation water applied, *i.e.,* 556 mm due to less depletion of moisture level, more frequent irrigation was needed. The total water used was calculated by taking the rainfall received and irrigation water used during the cropping season. Total amount of water used (irrigation + effective rainfall) was 575.3, 345.3, 206.3, 124.8 mm under

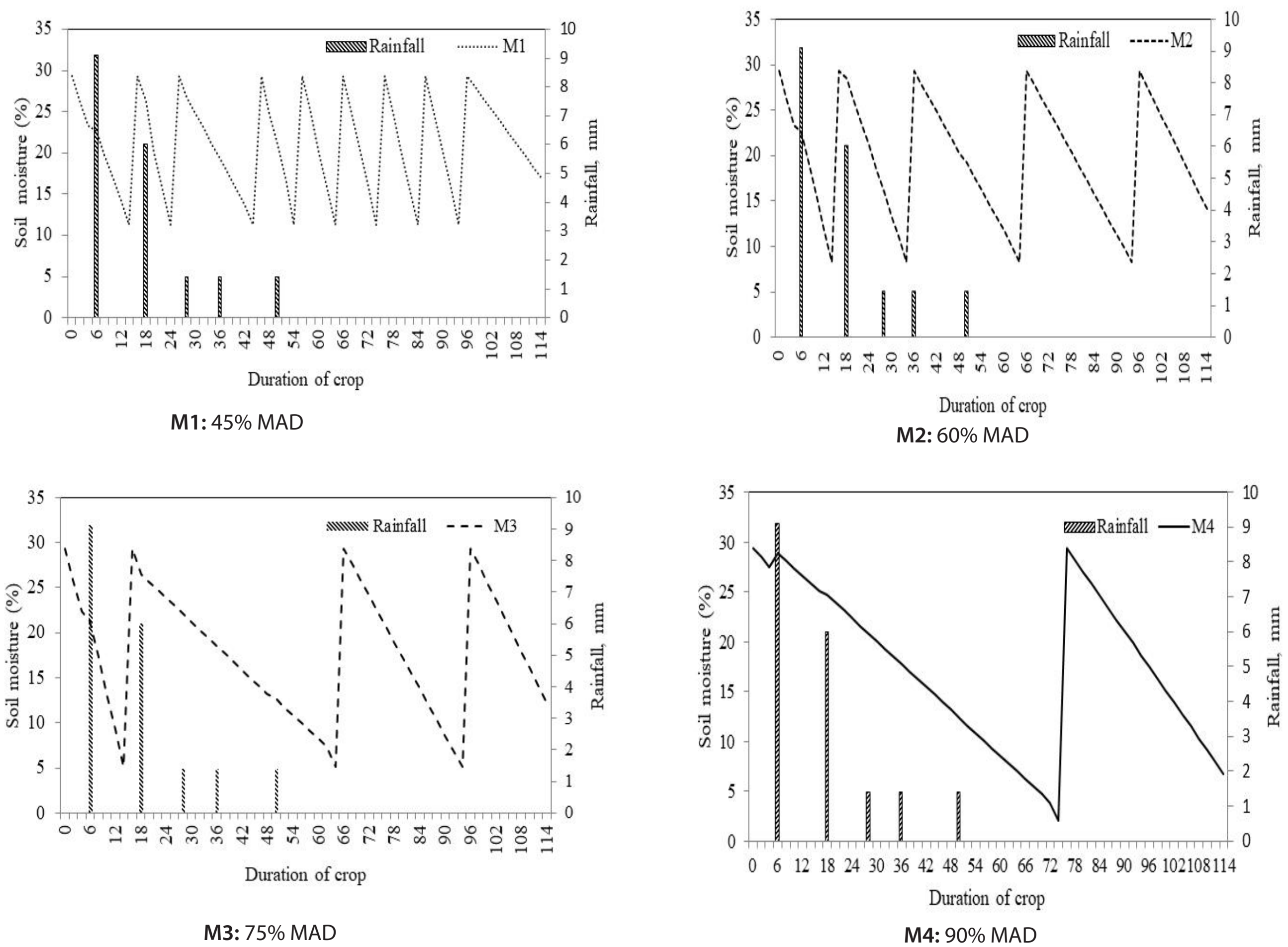

Fig 2 : Soil moisture variation at deficit irrigation regimes

M_1, M_2, M_3, and M_4, respectively. The variation of in-situ soil moisture under different treatment is shown in Fig.2.
(MAD = Maximum Allowable Depletion)

The variation of *in-situ* soil moisture was found to take a form of sinusoidal curve under different moisture regime as reported by various researchers (Dey *et al*., 2017; Marwein *et al*., 2017; Marwein and Ray, 2021; Mawthaoh *et al*., 2023).

Yield attributes and Yields

The effect of irrigation regimes and potato cultivars on yield and yield attributes and water productivity are shown in Table 3.

It may be noted that the yield and yield attributes were highest in treatment M1. Yield level in M1, M2 and M3 were 70.64, 44.79 and 27.55% more than M4 due to lesser depletion of available soil moisture from the root zone which might have contributed the enhanced final yield of potatoes. These findings can be supported from the previous findings of Yuan et al.(2003), Wang et al., (2006), Ray et al.(2011), Ierna and Mauromicale (2012), Sun et al.(2015), Kassu et al.(2017), King et al. (2020), Ray et al. (2023a, b). Similarly, the recorded values of water productivity under M4, M3 and M1 treatments were 170.23, 108.50 and 41.39% more than M1. The reason for highest water productivity in M4 was due to least amount of water usage, though it had the lowest yield. The M4 treatment received only one irrigation. It was received during the tuber bulking period, thus contributing a substantial increment of yield. Out of all the main plot treatments, M4 had the highest water productivity (75.34 kg ha-1 mm-1), over that of M3 (58.13 kg ha-1 mm-1), M2 (39.42 kg ha-1 mm-1), and M1 (27.88 kg ha-1 mm-1). The order of water productivity in main plot treatments was ranked M4>M3>M2>M1. Out of all the sub plot treatments, Kufri Jyoti had the highest water productivity (54.50 kg ha-1 mm-1), over both V2 (50.83 kg ha-1 mm-1) and V3 (45.23 kg ha-1 mm-1) and at par with that of Kufri Megha (50.83 kg ha-1 mm-1). These findings can be supported from the previous findings of Badr et al. (2012), Jha et al. (2017), Begum et al. (2018), Carli et al. (2014), Ray et al. (2017), Paredes et al. (2018), Sethi et al. (2022).

Similarly, it can be observed that irrigation during the vegetative growth in treatment M_1 was less influential in water productivity than irrigation during tuber bulking in treatment M_4. Irrigation during vegetative growth is associated with higher evapotranspiration loss due to higher LAI. Hence, the water stress during vegetative growth and application during critical period seems to be beneficial to increase water productivity at expense of yield decrement. Several previous studies also reports that water stress is associated with increase in water productivity (Ati *et al*., 2012, Sadawarti *et al*., 2013, Jha *et al*., 2017, Begum *et al*., 2018, Ahmadi *et al*., 2010; Ierna and Mauromicale, 2012, Carli *et al*., 2014, Paredes *et al*., 2018; Gujar *et al*., 2022). The significant difference in water productivity in sub plots was due to higher yield of potato cultivar kufri jyoti as compared to kufri metha and kufri giriraj at same level of water application.

The yield attributes, yield as affected by variety and irrigation schedule are presented in the Table 3. Higher irrigation enhances emergence of seed tubers, which influences the ultimate plant population. It results from distributing soil moisture uniformly and maintaining the ideal soil temperature required for emergence and establishment. The results are similar with those of previous researchers (Singh et al., 2008; Kumar and Bhatia, 2019; Wang et al., 2006; Wanniang et al., 2019; Mawthaoh et al., 2023). The tuber yield was significantly impacted by irrigation regimes, with treatment M1 (16.04 t ha-1) recording the maximum tuber yield compared to treatments M1, M3, and M4. Treatment M2 (13.61 t ha-1) and M1 (16.04 t ha-1) were statistically at par. With regard to sub plot treatments, Kufri Jyoti (13.73 t ha-1) considerably out performed Kufri Megha and Kufri Giriraj in terms of economic returns. However, Tuber yield in Kufri Jyoti (13.73 t ha-1) was statistically at par to that of Kufri Megha (12.96 t ha-1).

The yield levels in irrigation regimes viz., M1, M2, and M3 were found to be 70.64, 44.79, and 27.55% higher than those in M4. Due to larger plant populations, more tubers per plant, and larger tuber weights per plant, and tuber yield increases as water application increased. Tuber initiation and number of tubers per plant both increases when irrigation water was provided in suitable amounts (Shock et al., 1992). According to Onder et al. (2005), Amanulla et al. (2010), Kumar et al. (2007), Bisht et al. (2012), water stress is linked to a significant decrease in tuber numbers as against optimum soil moisture. The weight of the tubers increased with each irrigation once they are initiated (Eldredge et al., 1996; Shock et al., 1998). On the other hand, even though, treatment, M3 had half as much irrigation as treatment M2, it can be seen that the yield levels in M2 and M3 were statistically at par. Possible causes for this may be due to the fact that both the treatments received the same amount of irrigations (2) during the critical stage of the crop at stolon and tuber bulking. In the varietal treatments, the difference in yield was due to difference in varietal characters in terms of growth and yield attributes. Kufri Giriraj performed least in terms of all growth and yield parameters except tuber weight, which resulted in lower yield than Kufri Jyoti and Kefri Megha.

Conclusion

Understanding the soil moisture dynamics is essential for sustainable water management strategies that can mitigate the impacts of water scarcity in potato cultivation. The present field investigation revealed that, the variation of soil moisture is high under maximum available depletion of soil moisture and vice versa. Soil moisture in the root zone is one of the essential inputs for better growth and development of potato. Highest water productivity to a tune of 75.34 kg ha^{-1} mm^{-1} was recorded for 90% maximum allowable depletion irrigation regime. Similarly, Kufri Jyoti recorded highest yield to a tune of 13.73 t ha^{-1} which was statistically at par with Kufri Megha (12.96 t ha^{-1}). The farmers of Meghalaya may take up these varieties under water limiting scenarios to enhance water productivity to a greater extent.

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