

EFFECT OF DIFFERENT IRRIGATION FREQUENCIES AND METHODS ON PERFORMANCE OF POTATO IN NORTH-EASTERN GHATS OF ODISHA

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ABSTRACT: An experiment was conducted at CUTM, Odisha to evaluate the influence of different irrigation frequencies and methods on performance of potato. The experiment was designed in strip plot design with 4 irrigation frequencies and 3 irrigation methods together, replicated thrice. The significantly higher LAI at 60 DAP, haulm dry weight at 60 and 86 DAP, chlorophyll total at 60 and 75 DAP were recorded with 20 mm ET_c than all other irrigation frequencies. In case of irrigation methods, every furrow irrigation (EFI) showed significantly higher LAI at 60 DAP, dry weight of tubers at 86 DAP, arithmetic and geometric mean diameter of grade A tubers, chlorophyll total content at 60 and 75 DAP than all others. The maximum tuber yield was recorded with 20 mm ET_c which was statistically *at par* with 30 mm ET_c. But highest starch content was recorded under 30 mm ET_c and it was significantly decreased at 20 mm ET_c due to plenty of soil moisture under this treatment. Starch content was also decreased significantly under EFI than AFI due to the same fact. The tuber yield obtained under EFI was statistically *at par* with alternate furrow irrigation (AFI). According to the linear regression, proportionate tuber yield increase will be higher with decrease in the irrigation water use efficiency. The treatment combination, 20 mm ET_c-EFI showed highest gross return, net return and B:C which could be recommended for the potato growers in north-eastern ghats of Odisha. This was closely followed by the treatment combination, 30 mm ET_c-EFI or 20 mm ET_c-AFI and could also be adopted as a remunerative technique in the areas having water crisis.

KEYWORDS: Irrigation frequency; irrigation method; potato; water use efficiency; yield

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth largest food crop in the world followed by rice, wheat, and maize. This crop is acting as high-quality food with rich, comprehensive and balanced nutrition (FAO, 2022). In India, the area under cultivation of potato was 2.20 million hectares, production is 56.17 million tonnes along with an average yield of 25.50 t ha⁻¹ during the year, 2022 (Govt. of India, 2022). Odisha contributed around 0.50% of national potato area and 0.21% of national potato production along with the potato productivity of 10.62 t ha⁻¹ (APC, 2021-22).

The world's largest consumption of water sources is mainly interlinked with food crop production by utilizing irrigation water (Wahyuningsih *et al.*, 2021). One of the major technological constraints in potato cultivation is lack of assured source of irrigation (Nand and Kokate, 1990) and an economic constraint in adoption of potato cultivation technology is high irrigation cost (Lal *et al.*, 2011), which can be curtail by reducing the no. of irrigations. In this regard, (Shekhawat, 2001) has opined that potato cultivation would be a possible alternative to enhance the farm income, if efficient and reliable irrigation management strategies are adopted. Partial

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root zone drying (PRD) irrigation technique is an imperative strategy of conserving water and from the last 10 years, is highly adopted for agricultural crops to increase water productivity in crops in water scarce areas. PRD is a more efficient technique than deficit irrigation (DI) and can save agricultural water about 50% without showing decrement in production and enhance the quality of the produce as compared to conventional and deficit irrigation (Iqbal *et al.*, 2020). PRD induce new roots as a consequence of alternate drying and rewetting cycle, these newer roots increase hydraulic conductance (Kang *et al.*, 2000; Kang *et al.*, 2003). Alternate furrow irrigation (AFI) is a PRD technique (Sepaskhah and Kheradnam, 1977). Generally, irrigated furrows are alternated at every irrigation operation under AFI. If irrigated furrows are fixed by following permanent skip furrow irrigation (PSFI), more water may be saved by minimizing the wetting area and salts may accumulate on the dry side of the ridge (Onishi *et al.*, 2021).

Duration of alternating wet and dry sides has its own impact on the absorption of water. More than three days alternation drying of the soil can increase water absorption (Dodd *et al.*, 2006). Potato is a short-duration crop and sensitive to water stress because of its shallow root depth and distribution of around 85% of potato roots in the upper 30 cm of top soil (Dalla Costa *et al.*, 1997; Onder *et al.*, 2005; Ahmadi *et al.*, 2011; Gitari *et al.*, 2018a, b). Potato responds well to favorable amounts of soil moisture in excess or in case of deficit conditions decreasing crop productivity. Hence, by adopting the irrigation scheduling strategies, we can enhance the production of potatoes throughout the growing period (Kashyap and Panda, 2003), understanding its pattern of root uptake, water movement in the soil and evapotranspiration of crop (ET_c) which is essential to design the scheduling of

irrigation for the crop (Shankar *et al.*, 2009; Kumar *et al.*, 2013; Satchithanantham *et al.*, 2014; Paredes *et al.*, 2018). To enhance crop productivity while conserving resources at the same time, it has to support the need for more crops per drop of water (Mukherjee *et al.*, 2010). By combining the irrigation frequencies with methods, the number of irrigations to the crop can be minimized and the water use efficiency can be increased with the achievement of satisfactory tuber yield.

MATERIALS AND METHODS

Experimental site and design

The field experiment was performed at Post Graduate Research Farm of M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha during *Rabi*, 2023-24. The field was situated at 18°48' N latitude, 84°10' E longitude and altitude of 90 m above mean sea level. The crop received rainfall of 35.35 mm during the growing period, 90% of that was considered as effective rainfall (31.8 mm) as per U.S. Bureau of Reclamation method (Ali and Mubarak, 2017). The experimental soil was sandy loam in texture having pH 6.1, organic carbon 0.41% and initial soil status of available nitrogen, phosphorus, and potassium values were 240.4, 14, and 141 kg ha⁻¹, respectively. The experiment was designed in strip plot design with the treatments consisted of four irrigation frequencies at 20 mm ET_c , 30 mm ET_c , 40 mm ET_c and 50 mm ET_c as 1st factor and three different irrigation methods *i.e.*, every furrow irrigation (EFI) where all the furrows kept wetted, alternate furrow irrigation (AFI) where alternate furrows being wetted every time and permanent skip furrow irrigation (PSFI) by fixing the wetting furrows permanently, were taken as 2nd factor. In each occasion, 30 mm irrigation water was applied. The crop was planted on 4th November, 2023.

The crop was planted at row to row spacing of 60 cm and plant to plant spacing of 20 cm and net plot size was $6.6 \times 3.0 \text{ m}^2$.

Potato variety and fertilizer rate

The potato variety was used in this experiment was “Kufri Jyoti” which was of 90-110 days duration. Recommended dose of fertilizer was 120:60:120 kg ha⁻¹ N: P₂O₅: K₂O which was given through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

Chlorophyll and SPAD meter reading

Chlorophyll total was determined at 60 and 75 DAP by the formula (Pérez-Patricio *et al.*, 2018):

$$\text{Chlorophyll total (mg g}^{-1}\text{)} = (8.2 \times A663) + (20.2 \times A645)$$

Where, A663 and A645 were the absorbance value measured from 663 nm and 645 nm wavelength, respectively. The Spectrophotometer was adjusted to zero using the acetone mixture.

For measurement of relative chlorophyll content from leaf handheld Chlorophyll Meter SPAD 502 was used to obtain readings estimating chlorophyll concentration on the fourth or fifth leaf down from the top of the plant at 60 and 75 DAP. The SPAD reading of potato leaf was recorded at three locations: (a) about one-third of the leaf length from the petiole, (b) at the midpoint of leaf, and (c) about one-third of the leaf length from the apex (Lin *et al.*, 2010). Ten readings from each plot, were taken and averaged.

Tuber diameters

To find the mean size of potato tubers, three linear dimensions *i.e.*, length (L, mm), width (W, mm) and thickness (T, mm) were measured. The geometric mean diameter (mm) and the arithmetic mean diameter were

calculated as follows (Arfa, 2007; Elbatawi *et al.*, 2008; Abd Elhay, 2017):

$$\text{Geometric mean diameter (mm)} = \sqrt[3]{L \times W \times T}$$

$$\text{Arithmetic mean diameter (mm)} = \frac{L+W+T}{3}$$

All these dimensions were measured in a medium at room temperature (25°C).

Starch content

To measure the starch content, a fresh potato sample of 0.5 g was taken and the method mentioned by Mondal *et al.* (2021) was followed.

Soil moisture study

Soil samples were taken just before irrigation and 48 hours after irrigation from 0-20 and 20-40 cm depth with the help of the screw soil auger. Soil moisture from two different soil layers was calculated on oven dry weight basis as per the method mentioned by Singha *et al.* (2018).

The profile contribution of soil moisture was determined with the help of change of moisture status between sowing and harvesting of the crop (Qiu *et al.*, 2001). Bulk density of soil was 1.43 g cm⁻³ at 0-20 cm soil layer and 1.48 g cm⁻³ at 20-40 cm soil layer.

Total water use or actual evapotranspiration (AET or ET_c) was calculated as per soil water balance equation (Yang *et al.*, 2023):

$$\text{AET (mm)} = \text{Total applied irrigation water (mm)} + \text{Effective rainfall (mm)} + \text{Soil profile contribution (mm)}$$

Here, total impact of contribution of capillary rise and drainage was considered negligible.

$$\text{Water use efficiency (WUE)} = Y/\text{AET};$$

$$\text{Irrigation use efficiency (IUE)} = Y/\text{Total amt. of irrigation}$$

In both the cases, Y was calculated by considering the average of tuber yield and

irrigation water yield. Finally, Y was converted in kg ha^{-1} . WUE and IUE were expressed in kg m^{-3} .

$WUE_{ET} = Y_i - Y_{112} / I_i - I_{112}$; $WUE_I = Y_i - Y_{112} / \text{Total irrigation amount}$

Where, Y_i was the yield (kg ha^{-1}) of i th treatment combination, I_i was the amount of irrigation (mm) applied under i th treatment combination, Y_{112} was the yield (kg ha^{-1}) of 12th treatment combination; I_{112} was the irrigation amount (mm) of 12th treatment combination.

The irrigation dates and ET_c values at each irrigation was calculated (Gonzalez *et al.*, 2023) in Table 1:

Statistical analyses

All the data on growth parameters were taken periodically, yield attributing parameters and yield were taken at harvest and analyzed statistically at 5 per cent level of significance.

RESULTS AND DISCUSSION

Growth parameters of potato plants

The plant height, no. of shoots plant^{-1} and no. of leaves plant^{-1} at 86 DAP, leaf area index (LAI) at 60 DAP, dry weight of haulm at 60

and 86 DAP were significantly influenced by irrigation frequencies and methods (Table 1). At 86 DAP, highest plant height (71.2 cm), no. of shoots plant^{-1} (15.19) and no. of leaves plant^{-1} (47.70) were recorded 20 mm ET_c . Similarly, this treatment attained maximum LAI (3.50) at 60 DAP and haulm dry weight at 60 (236.09 g m^{-2}) and 86 DAP (515.88 g m^{-2}). There was no significant variation in no. of shoots plant^{-1} obtained under 20 and 30 mm ET_c . Previous report of Kumar *et al.* (2007) was in line with the results obtained for the no. of shoots plant^{-1} . Haulm dry weights were significantly increased under higher soil moisture regimes (Irfan *et al.*, 2015). This might be due to production of a greater no. of haulms, leaves and taller plants which ultimately increased plant weight (Yadav *et al.*, 2003). The higher soil moisture regime has encouraged stolonization during the entire growing period. These stolons being unable to go deep in the soil in order to develop a tuber and have become the haulms (Irfan *et al.*, 2015). But the height of plants (70.2 cm) and no. of shoots plant^{-1} (14.76) at 86 DAP obtained under 30 mm ET_c were statistically *at par* with 20 mm ET_c . That was might be due to the availability

Table 1. Details of crop evapotranspiration (AET or ET_c) based on irrigation frequencies.

Irrigation was given when ET_c value reached to							
20 mm (F_1)		30 mm (F_2)		40 mm (F_3)		50 mm (F_4)	
Date	ET_c (mm)	Date	ET_c (mm)	Date	ET_c (mm)	Date	ET_c (mm)
30/11/2023	18.52	03/12/2023	30.59	08/12/2023	39.79	11/12/2023	50.03
08/12/2023	21.28	14/12/2023	30.71	19/12/2023	39.33	28/12/2023	49.50
13/12/2023	21.51	24/12/2023	29.45	06/01/2024	39.68	23/01/2024	50.22
19/12/2023	21.51	07/01/2024	30.60	29/01/2024	39.83		
28/12/2023	20.40	24/01/2024	29.48				
06/01/2024	19.28						
16/01/2024	20.09						
29/01/2024	19.74						
Total irrigation	240 mm	150 mm		120 mm		90 mm	

*Crop coefficients (k_c) were taken from FAO K_c values of potato (Chapter 6 - ET_c - Single crop coefficient); Satisfactory plant emergence was noted down on 24th November, 2023 *i.e.*, 20 DAP.

of optimum soil moisture under 20 and 30 mm ET_c treatments during the crop growing period. Patel and Patel (2001); Kumar *et al.* (2007); Dash *et al.* (2018) also observed similar decreasing trend of plant height with lowering irrigation frequencies. At 30 DAP, LAI was non-significantly varied among irrigation frequencies and methods because ET_c based irrigation was not started at 30 DAP. The lowest values were obtained for plant height (65.3 cm), no. of shoots plant⁻¹ (13.21) and no. of leaves plant⁻¹ (42.74) at 86 DAP, LAI (3.00) at 60, haulm dry weight at 60 and 86 DAP (187.27 and 412.94 g m⁻², respectively) with irrigation at 50 mm ET_c . But all these data were statistically *at par* with 40 mm ET_c . Significant decrease in LAI at 80 DAP with decreasing irrigation frequency had been reported by Tyagi *et al.* (2012). Significant increase in dry weight of haulm with higher irrigation frequencies was also reported previously by Panigrahi *et al.* (2001). These were mainly due to amplifying effect of irrigation frequency on irrigation depth (Demelash, 2013). The no. of plants m⁻² at

86 DAP was not varied significantly due to various irrigation frequencies.

In case of irrigation methods, the tallest plants (71.4 cm) with higher no. of shoots plant⁻¹ (14.86) and no. of leaves plant⁻¹ (46.80) at 86 DAP, LAI (3.41) at 60, haulm dry weight at 60 (221.67 g m⁻²) and 86 DAP (472.58 g m⁻²) were recorded with EFI method. But the plant height (69.3 cm), no. of shoots plant⁻¹ (14.33) and no. of leaves plant⁻¹ (45.05) at 86 DAP, dry weight of haulm at 60 (203.78 g m⁻²) and 86 DAP (460.82 g m⁻²) recorded under AFI were statistically *at par* with EFI. This finding strengthened the fact that crop growth of potato is not significantly hampered with shifting of irrigation method from EFI to AFI. LAI at 60 DAP obtained under EFI (3.41) was significantly higher than AFI (3.09). LAI of potato obtained under traditional furrow irrigation varied significantly with other methods in the earlier report of Amer *et al.* (2016). Similarly, no. of shoots plant⁻¹ (13.73) at 86 DAP, no. of leaves plant⁻¹ (42.68) at 86 DAP, LAI (3.08) at 60 DAP, dry weight

Table 1. Growth parameters of potato plants as influenced by irrigation frequencies combined with irrigation methods.

Treatments	Plant height at 86 DAP (cm)	No. of shoots plant ⁻¹ at 86 DAP	No. of leaves plant ⁻¹ at 86 DAP	LAI		Dry weight of haulm (g m ⁻²)		No. of plants m ⁻² at 86 DAP
				30 DAP	60 DAP	60 DAP	86 DAP	
Irrigation frequencies								
20 mm ET _c (F ₁)	71.2	15.19	47.70	0.53	3.50	236.09	515.88	10.9
30 mm ET _c (F ₂)	70.2	14.76	45.33	0.46	3.22	210.48	478.47	11.2
40 mm ET _c (F ₃)	67.7	14.07	43.39	0.39	3.06	194.69	430.52	11.2
50 mm ET _c (F ₄)	65.3	13.21	42.74	0.36	3.00	187.27	412.94	10.7
S.Em. (±)	0.83	0.15	0.63	0.05	0.06	2.30	5.96	0.58
C.D. (P=0.05)	3.3	0.51	2.19	NS	0.22	7.95	20.61	NS
Methods of Irrigation								
EFI (M ₁)	71.4	14.86	46.80	0.46	3.41	221.67	472.58	11.3
AFI (M ₂)	69.3	14.33	45.05	0.43	3.09	203.78	460.82	10.8
PSFI (M ₃)	65.1	13.73	42.68	0.42	3.08	195.95	444.97	10.8
S.Em. (±)	1.04	0.28	0.93	0.03	0.05	5.25	5.79	0.53
C.D. (P=0.05)	3.6	1.11	3.24	NS	0.18	18.56	20.34	NS

*Dehaulming was done at 86 DAP

of haulm at 60 DAP (195.95 g m⁻²) and 86 DAP (444.97 g m⁻²) recorded with PSFI were significantly lower than EFI. The no. of plants m⁻² at 86 DAP was not varied significantly due to various irrigation methods.

Growth parameters of potato tubers

The fresh weight of tubers at 45, 60 and 75 DAP, dry weight of tubers at 60 and 86 DAP were varied significantly under different irrigation frequencies and methods (Table 2). Maximum tuber fresh weight at 45 (540.93 g m⁻²), 60 (1090.71 g m⁻²) and 75 DAP (1770.50 g m⁻²) and tuber dry weight at 60 (221.44 g m⁻²) and 86 DAP (550.83 g m⁻²) were recorded under 20 mm ET_c. But the fresh weight of tubers at 45 (515.65 g m⁻²), 60 (1029.23 g m⁻²) and 75 DAP (1669.35 g m⁻²) and dry weight of tubers at 60 (217.10 g m⁻²) and 86 DAP (540.05 g m⁻²) obtained under 30 mm ET_c were statistically *at par* with 20 mm ET_c. This was might be due to the availability of optimum soil moisture under 20 and 30 mm ET_c during the period of tuber bulking and growth. The lowest tuber fresh weights were obtained with

the irrigation frequency of 50 mm ET_c at all the dates of observation (398.25, 860.95, 1476.85 g m⁻² at 45, 60 and 75 DAP, respectively). But the results achieved at 60 (946.92 g m⁻²) and 75 DAP (1577.69 g m⁻²) under 40 mm ET_c were statistically *at par* with 50 mm ET_c. This result explored the chances of achieving statistically similar tuber yield under 40 and 50 mm ET_c.

In case of irrigation methods, the maximum tuber fresh weight at 45 (516.04 g m⁻²), 60 (1006.10 g m⁻²) and 75 DAP (1753.12 g m⁻²), tuber dry weight at 60 (217.39 g m⁻²) and 86 DAP (559.72 g m⁻²) were recorded with EFI which were significantly higher than PSFI (445.42, 949.29, 1511.38 g m⁻² of tuber fresh weight at 45, 60 and 75 DAP; 188.76 and 514.22 g m⁻² of tuber dry weight at 60 and 86 DAP). These results corroborated the fact that the tuber yield of potato significantly reduces when PSFI method is followed instead of EFI.

Chlorophyll total and SPAD reading

The chlorophyll total and SPAD values at 60 and 75 DAP were significantly influenced by irrigation frequencies and methods

Table 2. Growth parameters of potato tubers as influenced by irrigation frequencies combined with irrigation methods.

Treatments	Fresh weight of tubers (g m ⁻²)			Dry weight of tubers (g m ⁻²)	
	45 DAP	60 DAP	75 DAP	60 DAP	86 DAP
Irrigation frequencies					
20 mm ET _c (F ₁)	540.93	1090.71	1770.50	221.44	550.83
30 mm ET _c (F ₂)	515.65	1029.23	1669.35	217.10	540.05
40 mm ET _c (F ₃)	464.63	946.92	1577.69	206.67	536.66
50 mm ET _c (F ₄)	398.25	860.95	1476.85	177.43	507.93
S.Em. (±)	9.86	29.36	33.35	2.53	5.90
C.D. (P=0.05)	34.13	101.58	115.41	8.75	20.42
Methods of Irrigation					
EFI (M ₁)	516.04	1006.10	1753.12	217.39	559.72
AFI (M ₂)	478.13	990.46	1606.30	210.83	527.66
PSFI (M ₃)	445.42	949.29	1511.38	188.76	514.22
S.Em. (±)	12.71	15.80	52.91	3.65	8.14
C.D. (P=0.05)	42.91	55.55	187.75	12.78	28.49

*Dehaulming was done at 86 DAP

(Table 3). At 60 and 75 DAP, the significantly higher content of chlorophyll total (0.18 and 0.10 mg g⁻¹ at 60 and 75 DAP, respectively) were recorded by 20 mm ET_c than all other irrigation frequencies. SPAD (39.49 and 37.97 at 60 and 75 DAP, respectively) on both dates were measured highest under 20 mm ET_c which was statistically *at par* with 30 mm ET_c (38.53 and 35.92 at 60 and 75 DAP, respectively).

Similarly, at 60 and 75 DAP, the significantly higher results of chlorophyll total (0.16 and 0.09 mg g⁻¹ at 60 and 75 DAP, respectively) than all

others were recorded under EFI. But in case of SPAD, the values obtained under EFI (39.17 and 36.99 at 60 and 75 DAP, respectively) were statistically *at par* with the SPAD values obtained under AFI (38.68 and 36.01 at 60 and 75 DAP, respectively) on both dates.

From the interaction table (Table 3A), it was found that the combination of irrigation frequency, 20 mm ET_c with EFI method had significantly higher total chlorophyll content (0.14 mg g⁻¹) than all other treatment combinations at 75 DAP.

Yield attributes, arithmetic and geometric mean diameter of tubers

Most of the yield attributes were influenced significantly by the irrigation frequencies and methods (Table 4). The highest no. of tubers plant⁻¹ (4.9) at harvest was observed with the irrigation frequency of 20 mm ET_c which was statistically *at par* with 30 mm ET_c treatment (4.6). Similarly, the highest arithmetic (6.9 and 5.3 cm under grade A and B, respectively) and geometric mean diameters (6.5 and 5.0 cm under grade A and B, respectively) of grade A and B tubers were observed with 20 mm ET_c which were statistically *at par* with the arithmetic (6.7 and 5.0 cm under grade A and B, respectively) and geometric mean diameters (6.3 and 4.8 cm under grade A and B, respectively) of tubers obtained under 30 mm ET_c. Arithmetic and geometric mean diameter of C grade tubers were not varied significantly due to following the various irrigation frequencies and methods.

The no. of tubers plant⁻¹ at harvest was not varied significantly due to various irrigation methods. Earlier report of Onder *et al.* (2005) and Akram *et al.* (2020) supported this result. The maximum arithmetic mean tuber diameters were obtained under EFI method (6.9 and 5.2 cm under grade A and B, respectively) which were statistically *at par*

Table 3. Chlorophyll total and SPAD value of potato plants as influenced by irrigation frequencies combined with irrigation methods.

Treatments	Chlorophyll total (mg g ⁻¹)		SPAD value	
	60 DAP	75 DAP	60 DAP	75 DAP
Irrigation frequencies				
20 mm ET _c (F ₁)	0.18	0.10	39.49	37.97
30 mm ET _c (F ₂)	0.16	0.07	38.53	35.92
40 mm ET _c (F ₃)	0.14	0.05	38.03	36.33
50 mm ET _c (F ₄)	0.12	0.04	37.30	33.35
S.Em. (±)	0.002	0.004	0.45	0.72
C.D. (p = 0.05)	0.007	0.013	1.44	2.48
Methods of irrigation				
EFI (M ₁)	0.16	0.09	39.17	36.99
AFI (M ₂)	0.15	0.06	38.68	36.01
PSFI (M ₃)	0.14	0.05	37.16	34.67
S.Em. (±)	0.002	0.004	0.36	0.55
C.D. (p = 0.05)	0.007	0.013	1.28	1.83

Table 3A. Interaction effect of irrigation frequencies × irrigation methods on total chlorophyll content at 75 DAP.

Treatments	20 mm ET _c (F ₁)	30 mm ET _c (F ₂)	40 mm ET _c (F ₃)	50 mm ET _c (F ₄)	Mean
EFI (M ₁)	0.14	0.10	0.05	0.05	0.09
AFI (M ₂)	0.10	0.05	0.05	0.04	0.06
PSFI (M ₃)	0.07	0.05	0.04	0.03	0.05
Mean	0.10	0.07	0.05	0.04	
S.Em. (±)			0.006		
C.D. (p = 0.05)			0.019		

Table 4. Yield attributes of potato, arithmetic and geometric mean diameter of tubers as influenced by irrigation frequencies combined with irrigation methods.

Treatments	No. of tubers plant ¹ at harvest	Arithmetic mean diameter of tubers (cm)			Geometric mean diameter of tubers (cm)		
		Grade A (≥75 g sized)	Grade B (50≤75 g sized)	Grade C (25≤50 g sized)	Grade A (≥75 g sized)	Grade B (50≤75 g sized)	Grade C (25≤50 g sized)
Irrigation frequencies							
20mm ET _c (F ₁)	4.9	6.9	5.3	3.7	6.5	5.0	3.6
30mm ET _c (F ₂)	4.6	6.7	5.0	3.7	6.3	4.8	3.5
40mm ET _c (F ₃)	4.1	6.5	4.8	3.6	6.1	4.5	3.4
50mm ET _c (F ₄)	4.1	6.2	4.5	3.5	5.8	4.3	3.4
S.Em. (±)	0.10	0.09	0.12	0.13	0.12	0.12	0.11
C.D. (P=0.05)	0.36	0.31	0.40	NS	0.40	0.42	NS
Methods of Irrigation							
EFI (M ₁)	4.6	6.9	5.2	3.7	6.6	4.9	3.6
AFI (M ₂)	4.4	6.5	5.0	3.6	6.1	4.7	3.5
PSFI (M ₃)	4.3	6.3	4.5	3.5	5.9	4.3	3.4
S.Em. (±)	0.12	0.11	0.12	0.05	0.10	0.12	0.06
C.D. (P=0.05)	NS	0.44	0.47	NS	0.41	0.47	NS

*Dehaulming was done at 86 DAP

with AFI method (6.5 and 5.0 cm under grade A and B, respectively). In case of geometric mean diameter of tubers, highest result under grade A (6.6 cm) and B (4.9 cm) were recorded with the EFI method. Geometric mean diameter of grade B tubers obtained with the AFI method (4.7 cm) was statistically *at par* with EFI.

Yield

The haulm yield, tuber yield and total marketable tuber yield were differed significantly by applying different irrigation frequencies and methods (Table 5). The maximum haulm (15.56 t ha⁻¹) and tuber yield (21.25 t ha⁻¹) were noted down with treatment 20 mm ET_c which was statistically *at par* with 30 mm ET_c (14.97 and 20.25 t ha⁻¹ were the haulm and tuber yield, respectively) and significantly least tuber yield was noted down with 50 mm ET_c (18.06 t ha⁻¹) which was in agreement with the earlier report of Demelash (2013). The highest total marketable yield (18.75 t ha⁻¹) was recorded from 20 mm

ET_c which was statistically *at par* with 30 mm ET_c (17.75 t ha⁻¹).

In case of irrigation methods, the maximum tuber yield (21.01 t ha⁻¹) was obtained with EFI but this result was statistically *at par* with AFI (19.57 t ha⁻¹). Similar results were reported earlier by Sarker *et al.* (2019). Similarly, the tuber yield (18.50 t ha⁻¹) recorded with PSFI method was statistically *at par* with AFI but significantly lesser than EFI. Previous report of Onishi *et al.* (2021) supported this result. The significantly higher result of haulm yield (15.09 t ha⁻¹) was obtained with EFI method than all other irrigation methods. This was probably because of the adequate availability of soil moisture for prolonged period (Verma *et al.*, 2013) under EFI treatment.

Starch content

The starch content in tuber was influenced significantly due to different irrigation frequencies and methods. The highest starch content (18.50 mg g⁻¹) was recorded under 30 mm ET_c which was significantly higher

than all others (Table 5). Starch content of tuber was significantly decreased at 20 mm ET_c (17.26 mg g⁻¹) than 30 mm ET_c . Pahuja and Sharma (1982) reported likewise. This decrement in starch content was due to hydrolysis of starch into sugar at higher water supply (Irfan *et al.*, 2017).

But the starch content was recorded significantly higher in AFI method of irrigation (18.05 mg g⁻¹) than all other irrigation methods. Water deficit induced changes in the activities of major carbohydrate metabolizing enzymes shifting the tuber from

a starch synthesizing to a starch mobilization function (Shock *et al.*, 1992).

Graded tuber yield

The non-marketable tuber yield and yield of grade A and B tubers were varied significantly by various irrigation frequencies and methods (Table 5). Significant variation in non-marketable tuber yield and tuber yield of grade A and B due to different irrigation frequencies were also reported earlier by Irfan *et al.* (2015). The non-marketable (<25 g sized) tuber yield was found maximum with 50 mm ET_c (4.66) which was statistically *at par* with 40 mm ET_c treatment (4.46 t ha⁻¹). The maximum marketable yield of grade B (50≤75 g sized) tubers and grade A (≥75 g sized) tubers (6.45 and 7.07 t ha⁻¹, respectively) were recorded with 20 mm ET_c (Table 6). This treatment showed significantly higher marketable yield of grade A tubers than other treatments. But the yield of grade B tubers obtained under 30 mm ET_c (6.27 t ha⁻¹) were statistically *at par*

Table 5. Yield and starch content of potato as influenced by irrigation frequencies combined with irrigation methods

Treatments	Haulm yield (t ha ⁻¹)	Tuber yield (t ha ⁻¹)	Total marketable tuber yield (t ha ⁻¹)	Starch content (mg g ⁻¹)
Irrigation frequencies				
20 mm ET_c (F ₁)	15.56	21.25	18.75	17.26
30 mm ET_c (F ₂)	14.97	20.25	17.75	18.50
40 mm ET_c (F ₃)	14.18	19.20	14.74	17.87
50 mm ET_c (F ₄)	13.84	18.06	13.41	16.53
S.Em. (±)	0.19	0.32	0.36	0.10
C.D. (P=0.05)	0.66	1.10	1.25	0.35
Methods of Irrigation				
EFI (M ₁)	15.09	21.01	17.98	17.46
AFI (M ₂)	14.64	19.57	15.85	18.05
PSFI (M ₃)	14.19	18.50	14.66	17.11
S.Em. (±)	0.05	0.48	0.42	0.16
C.D. (P=0.05)	0.17	1.68	1.60	0.57

Table 5A. Interaction effect of irrigation frequencies irrigation methods on non-marketable tuber yield of potato (t ha⁻¹)

Treatments	20 mm ET_c (F ₁)	30 mm ET_c (F ₂)	40 mm ET_c (F ₃)	50 mm ET_c (F ₄)	Mean
EFI (M ₁)	1.62	1.89	3.72	5.27	3.12
AFI (M ₂)	2.93	2.60	4.97	4.38	3.72
PSFI (M ₃)	2.86	3.40	4.70	4.32	3.82
Mean	2.47	2.63	4.46	4.66	
S.Em. (±)			0.31		
C.D. (P=0.05)			0.96		

Table 6. Non-marketable and marketable tuber yield of potato as influenced by irrigation frequencies combined with irrigation methods.

Treatments	Non-marketable tuber yield (t ha ⁻¹) (<25 g)	Marketable tuber yield (t ha ⁻¹)		
		Grade A (≥75 g)	Grade B (50≤75 g)	Grade C (25≤50 g)
Irrigation frequencies				
20 mm ET _c (F ₁)	2.47	7.07	6.45	5.23
30 mm ET _c (F ₂)	2.63	6.37	6.27	5.11
40 mm ET _c (F ₃)	4.46	5.29	4.45	5.00
50 mm ET _c (F ₄)	4.66	4.54	3.90	4.97
S.Em. (±)	0.31	0.17	0.15	0.26
C.D. (P=0.05)	1.06	0.60	0.54	NS
Methods of Irrigation				
EFI (M ₁)	3.12	6.46	6.32	5.19
AFI (M ₂)	3.72	5.66	5.12	5.06
PSFI (M ₃)	3.82	5.33	4.36	4.98
S.Em. (±)	0.22	0.11	0.27	0.09
C.D. (P=0.05)	NS	0.39	0.96	NS

with 20 mm ET_c . Similar results were reported earlier by; Kashyap and Panda (2003); Irfan *et al.* (2015). Much more production of large sized tubers under 20 and 30 mm ET_c might be due to continuous and adequate supply of soil moisture throughout the crop growing season (Irfan *et al.*, 2015).

Maximum marketable yield of grade B and grade A tubers as well as total marketable tuber yield (6.32, 6.46 and 17.98 t ha⁻¹, respectively) were recorded when EFI method was followed. These results were significantly higher than all others. This was probably because of the adequate availability of soil moisture for prolonged period (Verma *et al.*, 2013) under this treatment.

The interaction effects of irrigation frequencies combined with irrigation methods for all the yields remained non-significant except for non-marketable tuber yield (Table 5A). The lowest non-marketable tuber yield (1.62 t ha⁻¹) was recorded with the combination of 20 mm ET_c and EFI method which was statistically *at par* with the non-marketable tuber yield (1.89 t ha⁻¹) recorded with the combination of 30 mm ET_c and EFI method (Table 5A). These findings supported the fact that potato plants need irrigation for development of high-quality tubers (Gültekin and Ertek, 2018).

Crop evapotranspiration and water use efficiency of potato

The maximum AET (299.93 mm) were recorded with treatment 20 mm ET_c due to the application of maximum amount of irrigation water (Table 7). Similarly, the highest water use efficiency (WUE) (43.6 kg m⁻³) was obtained with the irrigation at 20 mm ET_c . This was because of maximum tuber yield recorded under this irrigation frequency option. Highest field capacity (Fc) in the rootzone depth (33.3%), soil profile contribution (47.43 mm) and IUE (60.0 kg m⁻³) were recorded under the irrigation frequency of 50 mm ET_c . Crosby and

Wang (2021) reported similar result related to highest IUE. This might be due to increase in irrigation interval resulted in more soil water storage in the root zone depth and more contribution of that stored water during the entire crop growing period. The variation in IUE between 30 and 40 mm ET_c was 1.2 kg m⁻³. The earlier report of Crosby and Wang (2021) corroborated this result.

In case of irrigation methods, EFI recorded highest results in all the WUEs (*i.e.*, WUE, WUE_{*r*}, IUE and WUE_{ET} were 38.9, 17.5, 57.8 and 40.7 kg m⁻³, respectively) whereas, Fc in the rootzone depth was recorded maximum (32.7%) under AFI method of irrigation. AFI could be an alternative to EFI or PSFI in South Asian countries with limited irrigation water availability due to this fact (Sarker *et al.*, 2019). AET and soil profile contribution were found maximum (224.67 and 42.87 mm, respectively) under PSFI method of irrigation.

The interaction effect between irrigation frequencies and methods showed that highest amount of irrigation under I₁ and lowest amount of irrigation under I₁₂ treatment combination were responsible for these results. The opposite results were obtained for soil profile contribution where highest contribution had come from I₁₂ (52.28 mm) and lowest contribution had come from I₁ (23.28 mm) treatment combination. Again, WUE and WUE_{*r*} were recorded highest under I₁ treatment combination (44.4 and 32.4 kg m⁻³, respectively). But Fc in rootzone depth and WUE_{ET} were highest (34.2% and 56.9 kg m⁻³, respectively) under I₇ (F₃-M₁) treatment combination. IUE was recorded maximum (61.0 kg m⁻³) under the treatment combination I₁₀ (F₄-M₁) due to maximum proportionate yield increase with minimum irrigation water. Maximum AET (303.82 mm) was recorded under I₃ (F₁-M₃) treatment combination because of highest amount of irrigation water applied.

Table 7. Fc of soil moisture, AET, soil profile contribution, WUE, WUE_I, IUE and WUE_{ET} as influenced by irrigation frequencies combined with irrigation methods.

Treatments	Fc of soil moisture (%)	AET (mm)	Soil profile contribution (mm)	WUE (kg m ⁻³)	WUE _I (kg m ⁻³)	IUE (kg m ⁻³)	WUE _{ET} (kg m ⁻³)
Irrigation frequencies							
20 mm ET _c (F ₁)	31.2	299.93	28.13	43.6	32.2	54.4	51.6
30 mm ET _c (F ₂)	32.2	223.43	41.63	38.1	21.2	56.8	53.1
40 mm ET _c (F ₃)	32.0	186.68	34.88	37.3	13.6	58.0	54.4
50 mm ET _c (F ₄)	33.3	169.23	47.43	31.9	0.8	60.0	
Methods of Irrigation							
EFI (M ₁)	32.3	215.21	33.41	38.9	17.5	57.8	40.7
AFI (M ₂)	32.7	219.58	37.78	37.7	16.9	57.3	39.7
PSFI (M ₃)	31.6	224.67	42.87	36.6	16.5	56.8	38.9
Irrigation frequencies × Methods of irrigation							
I ₁ (F ₁ -M ₁)	30.7	295.08	23.28	44.4	32.4	54.6	51.9
I ₂ (F ₁ -M ₂)	32.6	300.88	29.08	43.4	32.2	54.4	51.5
I ₃ (F ₁ -M ₃)	30.5	303.82	32.02	42.8	32.0	54.2	51.3
I ₄ (F ₂ -M ₁)	31.4	219.54	37.74	39.0	21.6	57.1	53.9
I ₅ (F ₂ -M ₂)	33.8	222.48	40.68	38.3	21.2	56.8	53.1
I ₆ (F ₂ -M ₃)	31.4	228.28	46.48	37.1	20.9	56.4	52.2
I ₇ (F ₃ -M ₁)	34.2	180.88	29.08	38.9	14.2	58.6	56.9
I ₈ (F ₃ -M ₂)	30.8	186.68	34.88	37.2	13.5	57.9	54.1
I ₉ (F ₃ -M ₃)	31.1	192.48	40.68	35.8	13.0	57.4	52.1
I ₁₀ (F ₄ -M ₁)	32.8	165.34	43.54	33.2	1.8	61.0	
I ₁₁ (F ₄ -M ₂)	33.9	168.28	46.48	32.0	0.7	59.9	
I ₁₂ (F ₄ -M ₃)	33.2	174.08	52.28	30.6		59.2	

*Here, Fc: field capacity in rootzone depth during the entire crop growing period

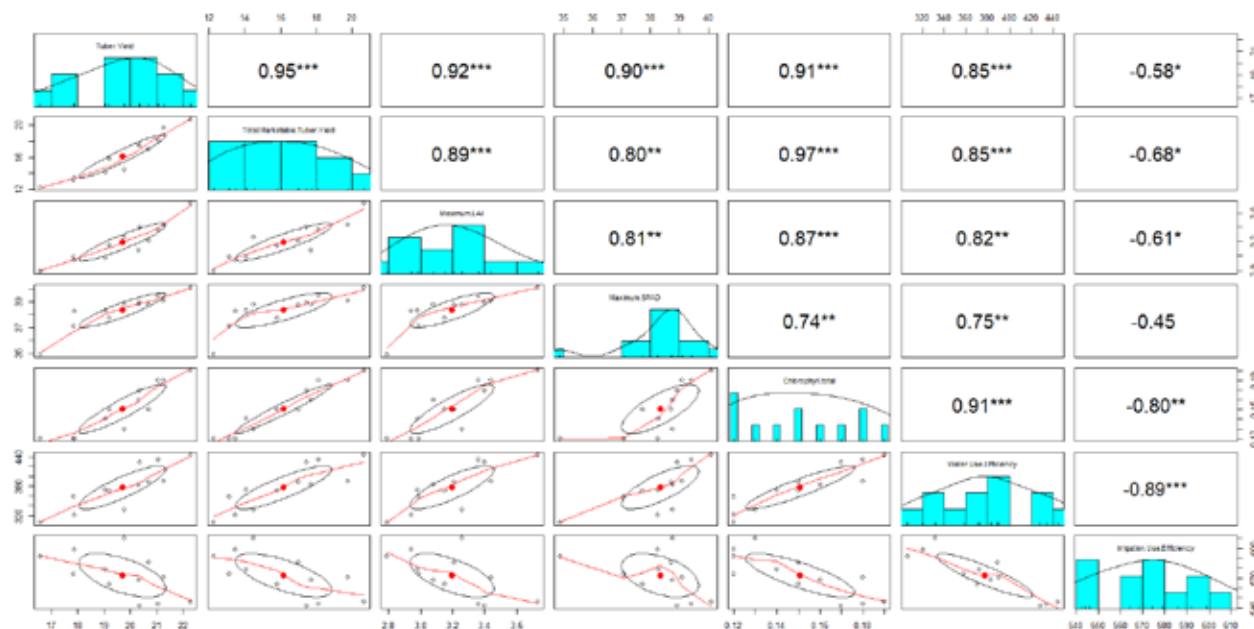
**Soil moisture just before planting of potato was 34.6%; One irrigation of 30 mm was given just after planting to all the plots for satisfactory germination

Correlation matrix

Tuber yield of potato showed very highly significant positive correlation with total marketable tuber yield (correlation coefficient, $r = 0.95^{***}$), maximum LAI (correlation coefficient, $r = 0.92^{***}$), maximum SPAD value (correlation coefficient, $r = 0.90^{***}$), highest chlorophyll total content (correlation coefficient, $r = 0.91^{***}$) and WUE (correlation coefficient, $r = 0.85^{***}$). But the IUE showed significant negative correlation (correlation coefficient, $r = -0.58^*$) with the tuber yield of potato (Table 8). This

result indicated that the IUE was increased significantly with the reduction of tuber yield. But tuber yield was enhanced when the results of other parameters were improved. The other parameters also showed very highly significant positive correlation with each other except IUE. The maximum SPAD value showed only strong significant positive correlation with maximum chlorophyll total content (correlation coefficient, $r = 0.74^{**}$) and WUE (correlation coefficient, $r = 0.75^{**}$) but no significant correlation with IUE (correlation coefficient, $r = -0.45$). The IUE also showed significant negative

Table 8. Correlation matrix among tuber yield (t ha^{-1}), total marketable tuber yield (t ha^{-1}), maximum LAI, maximum SPAD value, highest chlorophyll total content (mg g^{-1}), WUE (kg m^{-3}) and IUE (kg m^{-3}) of potato.



#Maximum LAI, SPAD value and chlorophyll total content (mg g^{-1}) was recorded at 60 DAP in this experiment.

*Correlation is significant at the 0.10 level

**Correlation is significant at the 0.05 level

***Correlation is significant at the 0.01 level

correlation with the total marketable tuber yield (correlation coefficient, $r = -0.68^*$) and maximum LAI (correlation coefficient, $r = -0.61^*$) whereas, a strong significant negative correlation was noted down between IUE and maximum chlorophyll total content (correlation coefficient, $r = -0.80^{**}$). These results indicated that the IUE was increased with the significant reduction of total marketable tuber yield and maximum LAI. But there was a highly significant decrease in chlorophyll total content occurred with the enhancement of IUE. Very strongly significant negative correlation ($r = -0.89^{***}$) was recorded in case of WUE versus IUE. This was due to the fact that profile contribution soil moisture fulfilled the water requirement of potato crop when irrigation interval was increased along with different methods of irrigation were followed.

Regression analysis of the tuber yield versus IUE

The functional relation between the IUE and tuber yield was expressed in the equation, $y = m \cdot x$ (Fig. 1). The value of regression coefficient (R^2) was 0.9889 which implied that around 99% of the tuber yield was contributed by the single factor, irrigation water management. Fabeiro *et al.* (2001) reported likewise. This strong regression was suggestive of the influence of IUE on the

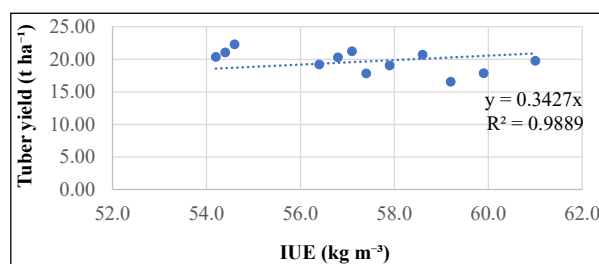


Fig. 1. Relationship between IUE (kg m^{-3}) and tuber yield (t ha^{-1})

tuber yield of potato. According to the linear regression, proportionate yield increase will be higher with decrease in the IUE which indicates that the higher amount of irrigation water is required than earlier for further enhancement of one unit in tuber yield.

Economics

Among the different irrigation frequencies, maximum cost of cultivation (₹ 78349 ha⁻¹) was obtained under irrigation at 20 mm ET_c and the cost of cultivation was obtained minimum under 50 mm ET_c treatment (₹ 76609 ha⁻¹). Similarly, maximum gross return (₹ 276186 ha⁻¹), net return (₹ 197838 ha⁻¹) and benefit-cost ratio (2.52) was obtained under irrigation at 20 mm ET_c treatment.

In case of irrigation methods, cost of cultivation (₹ 77986 ha⁻¹) was obtained maximum under EFI and the minimum (₹ 77007 ha⁻¹) under AFI and PSFI, both. The highest gross return (₹ 273071 ha⁻¹), net return (₹ 195085 ha⁻¹) and benefit-cost ratio (2.50) was obtained under EFI treatment.

The treatment combination, I₁ (F₁-M₁) showed highest cost of cultivation (₹ 79509 ha⁻¹), gross return (₹ 289907 ha⁻¹), net return (₹ 210398 ha⁻¹) and B:C ratio (2.65) (Table 9). Highest cost of cultivation was recorded under I₁ treatment combination due to highest amount of irrigation water application under this combination and achievement of highest tuber yield was responsible behind the highest gross and net return as well as B:C ratio under this treatment combination.

CONCLUSION

From this investigation, it can be concluded that the irrigation at 20 mm ET_c performed best in terms of growth and yield of potato. Similarly, the growth and yield of potato was better under every furrow method of irrigation than others. The treatment combination of 20 mm ET_c-EFI showed highest water use

Table 9. Economics of potato as influenced by irrigation frequencies combined with irrigation methods.

Treatments	*Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
Irrigation frequencies				
20 mm ET _c (F ₁)	78349	276186	197838	2.52
30 mm ET _c (F ₂)	77479	263314	185835	2.40
40 mm ET _c (F ₃)	76899	249626	172728	2.25
50 mm ET _c (F ₄)	76609	234791	158182	2.06
Methods of irrigation				
EFI (M ₁)	77986	273071	195085	2.50
AFI (M ₂)	77007	254370	177362	2.30
PSFI (M ₃)	77007	240497	163490	2.12
Irrigation frequencies × Methods of irrigation				
I ₁ (F ₁ -M ₁)	79509	289907	210398	2.65
I ₂ (F ₁ -M ₂)	77769	273793	196025	2.52
I ₃ (F ₁ -M ₃)	77769	264859	187090	2.41
I ₄ (F ₂ -M ₁)	78204	276342	198138	2.53
I ₅ (F ₂ -M ₂)	77116	263867	186751	2.42
I ₆ (F ₂ -M ₃)	77116	249731	172615	2.24
I ₇ (F ₃ -M ₁)	77334	269159	191826	2.48
I ₈ (F ₃ -M ₂)	76681	247689	171008	2.23
I ₉ (F ₃ -M ₃)	76681	232030	155349	2.03
I ₁₀ (F ₄ -M ₁)	76899	256877	179979	2.34
I ₁₁ (F ₄ -M ₂)	76464	232129	155665	2.04
I ₁₂ (F ₄ -M ₃)	76464	215367	138903	1.82

*The water application cost was taken @ ₹ 1.45 m⁻³ of water as reported earlier by Singha *et al.* (2018).

efficiency, gross return, net return and B:C ratio. Therefore, this treatment combination could be recommended for adoption by the potato farmers in north-eastern ghats of Odisha as a viable strategy to curtail the excess irrigation. This was closely followed by the treatment combination, 30 mm ET_c-EFI (2.53) or 20 mm ET_c-AFI (2.52) with respect to B:C ratio which can also be adopted as a remunerative technique in the areas having water crisis.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

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