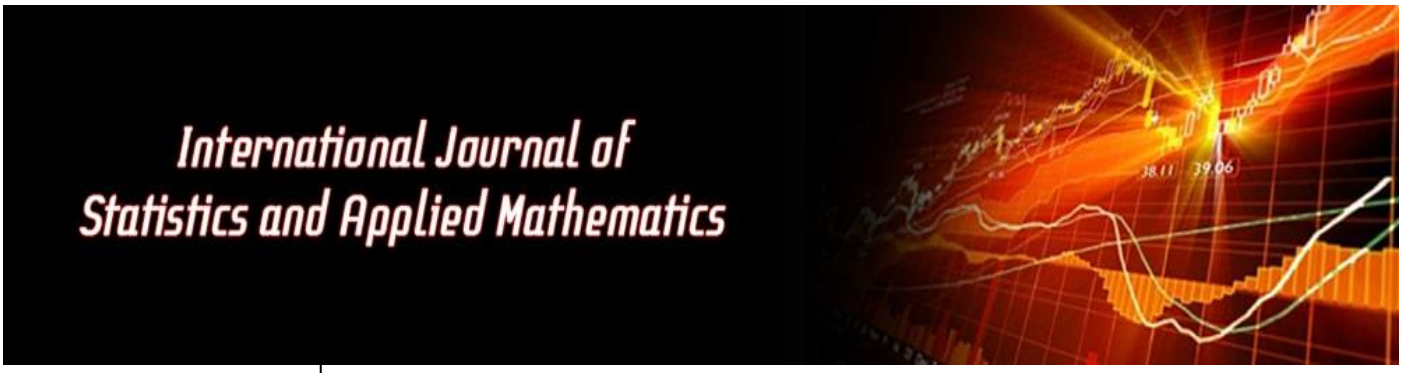

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Analyzing variation in water regimes and its effect on various plant growth and yield parameters of Potato (var. *Kufri Sindhuri*) in Valley areas of Manipur, India

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Abstract
Experiments conducted at College of Agriculture, Central Agricultural University, Imphal during the winter seasons of 2017-18 and 2018-19 recorded the performance of potato variety Kufri Sindhuri under three different irrigation regimes- 100% irrigation (I_1), 80% irrigation (I_2) and 60% irrigation (I_3) using drip irrigation. The results indicated that plants planted with 100% irrigation recorded maximum germination percentage (85.33%), plant height (45.03 cm), number of shoots plant^{-1} (5.64), stem girth (0.65 cm), crop growth rate (23.98 gm^{-2}day^{-1}), relative growth rate (3.10 gg^{-1}day^{-1}), weight of tubers per plant (1.29 kg) and tuber yield (23.34 t/ha) amongst other treatments.

Keywords: Potato, water regime, growth parameters, crop growth rate, relative growth rate, tuber yield

Introduction
Potato (*Solanum tuberosum L.*) is considered to be an indigenous crop of South America (Singh *et al.*, 2008) [1]. This crop originated from Peru and Bolivia (South America) and today it is cultivated around the globe. Potato is an economical food and is also a source of low-cost energy to the human diet. Potato is an important food crop of the world (Scott *et al*., 2000) [2] and is ranked fourth among the world's various agricultural crops in production volume, after wheat, rice and corn (Fabeiro *et al*., 2001; Bowen, 2003; Camire *et al*., 2009; Chakraborty *et al.*, 2010) [3-6] with a total production of 388 Mt from 19 Mha area. Potato is a short duration crop which is highly responsive to high inputs and capable to produce high yield. Asia and Europe accounting for more than 80% of world production are the world's major potato producing regions (Muthoni *et al*., 2011) [7]. The major producers in the world are China, India, Russia, United States, Ukraine, Poland, Germany, Belarus, Netherlands, United Kingdom, Canada, Turkey and Romania (FAO, 2005) [8]. Developing countries are responsible for more than half of the total world potato production in the world (FAO, 2009) [9] of which India is the second largest producer after China (Scot and Suarez, 2011; Saxena and Mathur, 2013) [10, 11]. In India potato is cultivated in about 2.17 Mha with a total production of 48.60 Mt (FAOSTAT, 2019) [12]. Potato is a herbaceous plant and requires light and frequent irrigation throughout the period of crop growth. In comparison with other food crops, it is very sensitive to water stress because of its shallow root system (Fabeiro *et al*., 2001; Iwama and Yamaguchi, 2006; Jabro *et al*., 2012) [3, 13, 14] and because of the low root to shoot ratio, which limit its capacity to extract water and nutrients from the soil (Harris, 1992) [15]. Potato yield is reduced by both over and under-irrigation. So, water management through water saving irrigation techniques during critical moisture period (germination, stolonization, tuberisation and bulking stages) is of utmost importance in commercial potato production. Consequently, the use of modern irrigation systems in irrigation operation and scheduling is essential for the reduction of irrigation water demands. Improved irrigation methods like drip method can save water without compromising potato yield or quality. Precise level of water applications leads to resource conservation, environmental and production benefits. Hence, a field trial using different levels of nitrogen application under different irrigation regimes using drip system of irrigation was taken up to ascertain the performance of potato.

Materials and Methods

The experiment was conducted at the experimental field of College of Agriculture, Central Agricultural University, Imphal during the winter season of 2017-18 and 2018-19 and laid out in factorial randomized block design with three replications. The soil of the experimental field was studied by the Bouyoucos Hydrometer method (Chopra and Kanwar, 1976) [16] and recorded clayey. It had a pH of 5.29 which was determined by the glass electrode pH meter (Jackson, 1973) [17]. The organic carbon content was determined by Walkley and Black rapid titration method (Piper 1966) [18] and was reported to be high (2.23%). Available nitrogen (282.73 kgha^{-1}), phosphorous (24.45 kgha^{-1}) and potassium (269.38 kgha^{-1}) were all recorded to be in the medium range and they were determined by the Alkaline permanganate method (Subbiah and Asija, 1956) [19], Bray and Kurtz method (Jackson, 1973) [17] and Flame Photometer method (Jackson, 1973) [17] respectively. The meteorological observations were collected from the Experimental Agromet Advisory Service, ICAR Complex for NEH Region, Manipur Centre, Lamphelpat, Imphal. The mean minimum and maximum temperature recorded during the cropping season was 4.6-6.5 ºC and 27.7-29.4 ºC respectively. The total rainfall recorded was 458.40.8 mm. The average relative humidity ranged from 36.6% (minm.) to 93.8% (maxm.). The experiment was laid out in factorial randomized block design and replicated thrice consisting of three irrigation regime treatments *viz*., 100% water availability (I_1) 80% water availability (I_2) and 60% water availability (I_3) respectively. Recommended dose of N, P and K (120/100/80: 80: 60 Kg N, P_2O_5 and K_2O kgha^{-1}) was applied in the form of Urea, SSP and MOP respectively. The entire quantity of fertilizer was applied at the time of sowing to all the plots equally. Bold and healthy potato tubers of variety *Kufri Sindhuri* were selected for planting.

Results and Discussion

Germination

Highest germination was observed in 100% irrigation regime (I_1) (85.33%) followed by 80% irrigation (I_2) (83.61%) and 60% irrigation (I_3) (79.67%) for both the years of study as well as on the mean pooled data. This may be due to the fact that more availability of water created a conducive environment for the tubers to grow unlike in I_3 in which there was less water availability. However, at 30 DAS more than 80% germination was observed in all the treatments. This is depicted in Table 1.

Table 1: Effect of irrigation regime on the germination (%) of potato

Treatments	Germination (%) 30 DAS		
	2017-18	2018-19	Pooled
I_1	84.56	86.11	85.33
I_2	83.22	84.00	83.61
I_3	79.33	80.00	79.67
SEd (±)	1.40	1.45	1.61
CD(p=0.05)	2.85	2.96	3.27

Plant height

Among irrigation regimes, 100% irrigation (I_1) produced significantly taller plants as compared to 80% irrigation (I_2) and 60% irrigation (I_3) at all levels of crop growth. At 30 DAS I_1 (17.52) recorded higher plant height than I_2 (16.02) and I_3 (11.78) for both the years of study as well as on the mean pooled data. At 60 DAS, I_1 (26.00) recorded significantly highest plant height over I_2 (24.41) and I_3 (20.95). At 90 DAS, I_1 (45.03) showed significantly highest plant height over I_2 (38.58) and I_3 (30.28). Similarly at maturity, I_1 (45.03) produced highest plant height over I_2 (38.75) and I_3 (30.49). This is depicted in Table 2. Increase in plant height may be because of application and the availability of more irrigation water through drip trickle irrigation system which allowed the plants to grow better and taller. Similar such results were also recorded by Fakhari *et al.* (2013) [20]. Consequently, I_3 recorded the lowest plant height during the course of the plant life. This may be attributed that the plant height reduced in response to water stress.

Table 2: Effect of irrigation regime on the plant height of potato

Treatments	30 DAS			60 DAS			90 DAS			Maturity		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
I_1	17.35	17.58	17.52	25.87	26.13	26.00	44.44	45.50	45.03	44.44	45.50	45.03
I_2	15.91	16.13	16.02	24.29	24.52	24.41	38.58	38.93	38.75	38.58	38.93	38.75
I_3	11.40	12.17	11.78	20.82	21.08	20.95	30.28	30.71	30.49	30.28	30.71	30.49
SEd(+)	0.30	0.30	0.31	0.50	0.49	0.47	0.66	0.67	0.69	0.66	0.67	0.69
CD(p=0.05)	0.61	0.62	0.63	1.02	1.00	0.96	1.35	1.37	1.39	1.35	1.37	1.39

Number of shoots per plant

100% irrigation (I_1) produced significantly higher number of shoots per plant of potato as compared to 80% irrigation (I_2) and 60% irrigation (I_3) at all levels of crop growth. At 30 DAS I_1 (2.39) recorded higher number of shoots per plant than I_2 (1.68) and I_3 (1.00) for both the years of study and on mean pooled data as well. This is depicted in Table 3. At 60 DAS, I_1 (5.01) recorded significantly highest number of shoots per plant over I_2 (3.39) and I_3 (1.26). At 90 DAS, I_1 (5.64) showed significantly highest number of shoots per plant over I_2 (3.82) and I_3 (1.58); Similarly at maturity, I_1 (5.64) produced highest number of shoots per plant over I_2 (3.82) and I_3 (1.58). I_1 provided water to the plants more frequently than I_2 and I_3 which increased plant growth resulting in tall plants with more numbers of shoots. These results coincided with the works of Amanulla *et al*. (2010)[21]. Under limited moisture supply most of the accumulated photosynthate was translocated into roots for its growth and development. It restricted the above ground growth of canopy. The number of shoots plant^{-1} decreased as the amount of irrigation water decreases.

Table 3: Effect of irrigation regime on the number of shoots per plant of potato

Treatments	30 DAS			60 DAS			90 DAS			Maturity		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
I_1	2.25	2.53	2.39	5.08	4.94	5.01	5.47	5.81	5.64	5.64	5.81	5.64
I_2	1.44	1.92	1.68	3.42	3.36	3.39	4.22	3.42	3.82	3.82	3.42	3.82
I_3	1.00	1.00	1.00	1.31	1.22	1.26	1.58	1.58	1.58	1.58	1.58	1.58
SEd(+)	0.06	0.08	0.08	0.13	0.14	0.15	0.11	0.15	0.13	0.15	0.15	0.15
CD(p=0.05)	0.11	0.17	0.16	0.26	0.27	0.30	0.23	0.30	0.26	0.30	0.30	0.30

Stem girth

Among irrigation regimes, 100% irrigation (I_1) produced significantly higher stem girth (cm) of potato as compared to 80% irrigation (I_2) and 60% irrigation (I_3) at all levels of crop growth. This is depicted in Table 4. At 30 DAS I_1 (0.45 cm) recorded higher stem girth (cm) than I_2 (0.39 cm) and I_3 (0.31) for both the years. At 60 DAS, I_1 (0.59) recorded significantly highest stem girth (cm) over I_2 (0.51) and I_3 (0.39). At 90 DAS, I_1 (0.75) showed significantly highest stem girth (cm) over I_2 (0.60) and I_3 (0.46); Similarly at maturity, I_1 (0.65) produced highest stem girth (cm) per plant over I_2 (0.50) and I_3 (0.36). I_1 provided water to the plants more frequently than I_2 and I_3 which produced thicker stems. Moisture deficits during root initiation period induce lignification of adventitious root and hampers potato growth (Belehu and Hammes 2004) [22]. This process is exacerbated under high soil temperature conditions. The stem girth increased with an increase in irrigation regime rate.

Table 4: Effect of irrigation regime on the stem girth of potato

Treatments	30 DAS			60 DAS			90 DAS			Maturity		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
I_1	0.40	0.49	0.45	0.52	0.67	0.59	0.68	0.82	0.75	0.58	0.72	0.65
I_2	0.35	0.43	0.39	0.46	0.56	0.51	0.54	0.66	0.60	0.44	0.56	0.50
I_3	0.27	0.34	0.31	0.34	0.44	0.39	0.41	0.50	0.46	0.31	0.40	0.36
SEd(+)	0.015	0.018	0.017	0.019	0.024	0.022	0.023	0.019	0.024	0.021	0.019	0.020
CD(p=0.05)	0.031	0.036	0.034	0.039	0.050	0.044	0.047	0.039	0.048	0.042	0.039	0.040

Crop growth rate

Among irrigation regimes, 100% irrigation (I_1) produced significantly more CGR ($gm^{-2}day^{-1}$) of potato as compared to 80% irrigation (I_2) and 60% irrigation (I_3) at all levels of crop growth. This is depicted in Table 5. During 30-60 DAS I_1 (6.37) recorded higher CGR ($gm^{-2}day^{-1}$) than I_2 (4.22) and I_3 (4.18) for both the years of study and in pooled data as well. I_2 and I_3 were statistically at par. During 60-90 DAS, I_1 (19.32) recorded significantly highest CGR ($gm^{-2}day^{-1}$) over I_2 (17.86) and I_3 (6.24); Similarly, during 90 DAS-maturity, I_1 (23.98) produced highest CGR ($gm^{-2}day^{-1}$) over I_2 (11.55) and I_3 (12.12). Irrigation water and fertilizers can be efficiently utilized in to promote the photosynthetic production efficiency of leaves that would enhance the dry matter accumulation and in turn, crop growth rate (Camargo et al., 2015; Ierna and Mauromicale, 2018) [23, 24].

Table 5: Effect of irrigation regime on the Crop Growth Rate of potato

Treatments	30-60 DAS			60-90 DAS			90 DAS-Maturity		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
I_1	6.32	6.42	6.37	19.24	19.41	19.32	23.43	24.54	23.98
I_2	4.20	4.24	4.22	17.52	17.86	17.69	11.69	11.40	11.55
I_3	4.15	4.21	4.18	6.22	6.27	6.24	11.93	12.31	12.12
SEd(+)	0.134	0.135	0.120	0.545	0.624	0.332	0.312	0.379	0.354
CD(p=0.05)	0.271	0.275	0.244	1.108	1.267	0.675	0.633	0.771	0.719

Relative Growth rate

Among irrigation regimes, 100% irrigation (I_1) produced significantly more RGR ($gg^{-1}day^{-1}$) of potato as compared to 80% irrigation (I_2) and 60% irrigation (I_3) at all levels of crop growth. This is depicted in Table 6. During 30-60 DAS I_1 (2.37) recorded higher RGR ($gg^{-1}day^{-1}$) than I_2 (2.25) and I_3 (2.12) for both the years of study and on mean pooled data as well. During 60-90 DAS, I_1 (2.82) recorded significantly highest RGR ($gg^{-1}day^{-1}$) over I_2 (2.76) and I_3 (2.44). I_1 and I_2 were statistically at par. During 90 DAS-maturity, I_1 (3.10) showed significantly highest RGR ($gg^{-1}day^{-1}$) over I_2 (2.91) and I_3 (2.76). RGR was found increasing significantly at a regular trend and reached maximum during 90-DAS-maturity in case of irrigation regimes (I). Similar such results were reported by Camargo *et al*., (2015) [23]. This may be due to non-stressed conditions and availability of sufficient water around plants exposed to I_1 treatment as compared to I_2 and I_3.

Table 6: Effect of irrigation regime on the Relative Growth Rate of potato

Treatments	30-60 DAS			60-90 DAS			90 DAS-Maturity		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
I_1	2.37	2.37	2.37	2.82	2.82	2.82	3.09	3.10	3.10
I_2	2.24	2.25	2.25	2.75	2.76	2.76	2.91	2.91	2.91
I_3	2.11	2.12	2.12	2.43	2.44	2.44	2.75	2.76	2.76
SEd(+)	0.038	0.042	0.040	0.051	0.045	0.045	0.049	0.049	0.052
CD(p=0.05)	0.077	0.085	0.082	0.103	0.091	0.091	0.100	0.100	0.106

Weight of tubers per plant

Among irrigation regimes, 100% irrigation (I_1) produced significantly more weight of tubers per plant (kg) of potato (1.29) as compared to 80% irrigation (I_2) (1.08) and 60% irrigation (I_3) (0.49) at the time of harvest for both the years of study and the pooled data. This may be due to high availability of soil moisture near the root zone due to scheduling irrigation at 100% water availability in I_1 which allowed higher efficiency of translocation of plant food from the source to sink. Irrigation reduction during vegetative, tuber formation and maturation stages causes yield loss. This is depicted in Table 7.

Table 7: Effect of irrigation regime on the Weight of tubers per plant

Treatments	Weight of tubers per plant (kg)		
	2017-18	2018-19	Pooled
I_1	1.29	1.30	1.29
I_2	1.07	1.08	1.08
I_3	0.47	0.51	0.49
SEd(+)	0.02	0.02	0.02
CD(p=0.05)	0.03	0.03	0.03

Tuber Yield

Among irrigation regimes, 100% irrigation (I_1) produced significantly more tuber yield (t ha^{-1}) of potato (23.34) as compared to 80% irrigation (I_2) (19.43) and 60% irrigation (I_3) (11.96) at the time of harvest. The higher results indicated that crop yield was positively correlated with the increased amount of irrigation water applied and tuber yield. Higher moisture content enhanced the plant growth which enhance the photosynthetic rate, enhance dry weight of tuber and finally increased the tuber yield. Soil water limitation in I_3 at different stages of growth results less tuber yield. This is depicted in Table 8.

Table 8: Effect of irrigation regime on the Tuber Yield of potato

Treatments	Tuber Yield (t ha^{-1})		
	2017-18	2018-19	Pooled
I_1	22.50	24.17	23.34
I_2	19.05	19.82	19.43
I_3	11.90	12.19	11.96
SEd(+)	0.41	0.59	0.45
CD(p=0.05)	0.83	1.21	0.91

Conclusion

Among all the water regime treatments, significantly higher plant growth and yield parameters was obtained by maintaining irrigation regime at 100% water availability (I_1) followed by 80% water availability (I_2). It is worth to note that 60% water availability significantly decreased crop growth and yield (I_3). This study reflects that when winter potato is planted with I_1 in Manipur region using drip irrigation technique, it can prove to be economically profitable to the farmers of this region. So, for yield optimization, growing potato with appropriate irrigation regime is very critical as we can get healthy plants with good growth and yield. I_1 had higher germination percentage, plant height, number of shoots $plant^{-1}$, stem girth, crop growth rate, relative growth rate, weight of tubers per plant, tuber yield amongst other treatments.

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