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EFFECT OF IRRIGATION LEVELS ON THE GROWTH, YIELD AND QUALITY OF POTATO

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Abstract

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Water significantly affects the high yield crop production of potato and is needed in sufficient amount to ensure optimum yield. To investigate the effect of different irrigation water quantity on the potato crop growth, yield and other agronomic components, a field experiment was conducted during the winter season of 2008-2010 on the eastern side of the Nile River, about 54 km north of Khartoum, Sudan. In the concerned experiment a randomized complete block design (RCBD) was used, where four different seasonal irrigation treatments were applied during the first season (Fs) while six were applied during the second season (Ss) through furrow irrigation system. The results showed that the growth parameters and the yield were significantly response ($P < 0.05$) to the seasonal water supply. The tuber yield was increased during the first season on the behalf of water supplied as compared to other**.**

Key words: water quantity, potato, growth, yield

Introduction

The aim of effective and efficient watering of a growing crop is to replenish depleted soil moisture at a given time to avoid physiological water stress in the growing plants. Furrow irrigation method is a commonly used for potato *(Solanum tuberosum* L.) irrigation in Sudan, due to cost-effectiveness and low maintenance requirements of the method. Generally potato is grown in the winter season in the eastern, northern and central regions of Sudan through utilization of furrow irrigation. In recent years, the center pivot irrigation is used in the River Nile State. Globally, potatoes are grown under irrigation in arid and semi-arid regions. Water requirements of the potato plant has been the subject of many research works. It is given more attention as one of the key factors affecting potato yield (Beukema and Van der Zaag, 1990). Presently, the area of land under potato cultivation in Sudan approximately 15 000 ha (Baldo et al., 1999), with an average yield range of 5-30 tons/ha (Mohamedali, 1989).

Due to the difficulty of measuring the plant water requirements accurately under field conditions, theoretical methods such as the Blaney-Criddle and Penman methods have been developed to predict the amount of irrigating water required (crop evapotranspiration) based on climatic data. The Blaney-Criddle method has been recommended for areas where temperature and daylight hour's data are available (Penman, 1948; Blaney and Criddle 1950; Allen et al., 1998). This method is more suitable for arid regions. The Penman method had been adopted for areas where data on temperature, humidity, wind and sunshine duration or radiation are available.

The determination of irrigating water amounts required for crop are important for estimating the quantity of water for plant growth, in order to have better water saving and water management. Therefore, this study was undertaken to investigate the effect of different amount of irrigation water on yield and yield characteristics of potato. Also the Blaney-Criddle and Penman methods were compared.

Materials and Methods

Study site and field conditions

The study was conducted at North Khartoum State at the Wadramli agricultural project (late. 16°11'N, long. 32°58') dur-

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ing the winter growing seasons (2008-2010). The climate of the study area is semi-arid with relatively cool winters and hot summers, and average rains of 160 mm falling between June and September. The winter season lasts from November to March, with maximum temperature 24–32°C and minimum of 18°C. The dominant soil type of the experimental site is clay with low percentage of organic matter.

Yield data

The potato cultivar *Alpha* was used for experimental plots comprising 5 rows, spaced at 0.75 m with tubers planted in row-seed spacing of 28-30 cm, for 12 m long. The outer ridge per plot was used as a guard row to avoid horizontal soil water movement. Seed tubers of uniform size were planted in November 29th, November 17th in the Fs and Ss respectively. Recommended fertilization and other cultural practices were carried out as needed. Half the recommended dose of urea (46% N) and all the superphosphate (48% P_2O_5) were applied at planting at the rate of 238 kg/ha. The second dose of urea was applied six weeks after planting. Earthing-up, weeding and control of pests were carried out during the study.

Nine weeks after planting, a random sample of plants was taken from each plot to determine the fresh and dry weights of haulm (stems and leaves), roots and tubers per plant, leaf area index (LAI), number and fresh weights of leaves and stems, number of stolons and tubers, and percentage of tuber set per plant. Data were also collected on the total and marketable yield of tubers as well as yield components. At crop maturity, the middle ridge was harvested on March 15th and on February 16th in the first and second seasons respectively, to assess the total yield.

Experimental design and irrigation treatments

The water treatments were arranged in a randomized complete block design in which 500, 600, 700, and 800 mm/season were applied in the first season (Fs) for ten irrigations and 240, 320, 400, 480, 560 and 640 mm/season were applied in the second season (Ss) for eight irrigations. The quantity of irrigating water required in each treatment was applied using the parshall flume device of 50 mm throat width. The Parshall flume was provided with two scales, H_a and H_b, for measuring the discharge of water. After reading the scale, the discharge of the device (liter/sec.) was obtained from the relevant calibration curve, based on the method developed by Michael (1978), as: $Q = 25.733\ (H_a - H_b)$, where Q is the discharge of water (liter. /sec), H_a is upstream section and H_b is the downstream section.

Crop evapotranspiration was predicted using the modified Blaney-Criddle and Penman methods based on meteorological data of Wadramli area obtained from the Sudan meteorological station (Table 1).

The modified formula of Blaney-Criddle equation (Doorenbos and Pruitt 1977) used in this study is: $ET_\circ = C[P\ (0.6\ T + 8)]$, where, $ET_\circ$ is the reference crop evapotranspiration (mm/day) for the month considered; T is the mean of daily temperature in °C over the month considered, PP is the mean of daily percentage of total daytime hours for a given month and latitude and C is the adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates. Meanwhile, the modified formula of Penman equation (Doorenbos and Pruitt, 1977) was used in this study is:

$$ET_\circ = C[W \cdot\ R_n\ + (1 - W) \cdot f(u) \cdot (ea - ed)],$$

Table 1
Means of monthly meteorological data for crop water requirement in 2008/2009 and 2009/2010 seasons

Month	Mean temp., °C	Mean RH, %	MWS* (m/h) at 2 m height		Sunshine, h
			Day	Night	
2008/2009 season					
November	24	27.7	5.06	5.01	10.1
December	21.6	30.7	25.23	4.21	11.2
January	22.8	28.7	5.72	4.46	10.2
February	24.7	27.4	6.36	4.72	10
March	27.6	13.2	7.58	5.64	9.8
2009/2010 season					
November	32.3	27.7	5.06	5.01	10.1
December	21.6	30.7	5.23	4.21	11.2
January	25	31.7	6.31	5.33	10.8
February	23.4	19.2	5.64	4.87	10

MWS* (Mean wind speed)

where ET_o is the reference crop evapotranspiration in mm/day, W is the temperature related weighted factor, R_n is the net radiation in equivalent evapotranspiration mm/day, $f(u)$ is the wind-related function, $(ea - ed)$ is the difference between the saturated vapour pressure at mean air temperature and the mean actual vapour pressure of the air both in bar, C is the adjustment factor to compensate for the effect of day and night weather conditions.

The crop evapotranspiration (ET_c) was calculated for both methods using the following formula (Allen et al., 1998) $ET_c = K_c \cdot ET_o$, where ET_c is crop evapotranspiration, K_c is the crop coefficient which varies with crop, stage of growth, growing season and weather condition and ET_o is the reference crop evapotranpiration, from Blaney-Criddle and Penman equations above.

Data analysis

Data collected was analyzed using the Statistical Package of Social Sciences (SPSS) version 16. Results considered significant when P-value > 0.05.

Results and Discussion

Plant growth parameters

The fresh and dry weights of haulm and roots per plant (Table 3) were not different among irrigation water treatments in the Fs; whereas, differences were significant (p > 0.05) in the Ss. Among Ss there was an increased trend for these growth parameters in response to increased amounts of irrigation water. The lowest value was given by 240 mm, and the highest value was given by 640 mm. Such discrepancy could be attributed to the clay loam nature of the soil at the site of the experiment; this led to water logging with 700 and 800 mm water quantities, which retarded vegetation growth. These results agreed with previous results reported by Islam et al. (1990), who found that, increasing soil moisture up to a limit is depending on soil type and nature. Regarding the results of fresh weight of tubers per plant, the difference among watering treatments in the Fs was not significant, but the difference was significant (p > 0.05) in the Ss (Table 2). The maximum effect was obtained from 600 mm in the Fs and 640 mm in the Ss respectively. In Ss, fresh weight of tubers showed an increased trend with increased irrigation water except for 560 mm.

The number and fresh weight of leaves were not significantly affected by the different amounts of irrigation water treatments in both seasons (Table 3); although there was a slight increase with increasing irrigation water quantity up to 600 mm level. Water treatments had no effect on the number and fresh weight of stems in Fs but the effect was significant in Ss. In contrast with these findings, Islam et al. (1990) reported significant effects of irrigation water quantities on the number of stems of the potato plant; however, others Lynch and Tai (1979) showed that the number of stems per plant was mainly determined by the size of the seed tuber and by the soil type.

For leaf area index LAI, application of different water quantity had no significant effect on LAI in the Fs, but the effect was significant in the Ss (Table 3). More precisely there was a slight increment in LAI till 600 mm, then after a de-

Table 2
Effect of quantity of applied irrigation water on haulm fresh and dry weight, roots and fresh weight of tubers per plant

Water applied, mm	Weight of haulm, g		Weigh of roots, g		Fresh weight of tubers, g
	Fresh	Dry	Fresh	Dry	
2008/2009 season					
500	128.4	18.5	3.6	1.2	176.7
600	178.9	21.9	4.3	1.6	208.5
700	138.7	18.8	3.2	1.2	177.9
800	143.9	21.1	4.3	2	173
SE±	11.31	1.95	0.62	0.29	39.1
2009/2010 season					
240	278.7	61.8	10.2	2.2	282.1
320	343.2	75.6	10.7	2.5	503
400	411.8	87.7	12.3	2.7	640
480	498.3	109.2	13.9	3.7	829
560	404.2	88.9	16.5	3.8	641.1
640	521.1	118.1	17	4	845
SE±	37.85	16.03	1.4	0.71	130.2

crease with an increased amount of applied water quantity in Fs, while the effect was positive and significant till 640 mm in Ss. This may be due to the clayey nature of the soil; irrigation levels of more than 600 mm might cause water logging and consequently affected LAI. Frequent irrigation in light-textured soils has been reported to increase LAI of the potato crop significantly (Islam et al., 1990). The number of stolons and tubers per plant percent tuber set, presented in Table 3, exhibited the same trend of vegetative growth components mentioned above, i.e. water amounts in the Fs did not significantly affect yield components which, however, responded significantly to lower rates in the Ss. These results indicated that for maintaining more stolons and tubers per plant, adequate soil moisture (640 mm) would be needed by the plant, while both excess (> 640 mm) and deficit (< 400 mm) watering have negative effect. Levy (1983) concluded that the number of tubers per plant tended to decrease in response to water stress. However, Haverkort et al., (1990) claimed that the number of tubers per stem was greatly increased or remained unchanged as a result of soil moisture stress.

Effect of water on Potato total tuber and marketable yields

Total and marketable yields in the Fs were insignificantly affected by water quantity applied (Figure 1). The highest value (19.9 tons/ha.) was obtained from 600 mm followed by 700 mm (15.5 tons/ha.), 800 mm (14.6 tons/ha.) and 500 mm (14.3 tons/ha.) indicating that both excess and deficit water had adverse effects on yield. The moderate water quantity (600 mm) was the optimum. In the Ss, differences in the total and marketable yields corresponding to quantity of water

Table 3

Effect of quantity of irrigation water applied on number and fresh weight of leaves, stems/plant, LAI, number of stolons, tubers and percentage tuber set/plant

Water applied, mm	Tuber set, %	No. of tubers	No. of stolons	LAI	Fresh stems weight, g	No. of stems	Fresh leaves weight, g	No. of leaves
2008/2009 season								
500	56	5.6	10	1.7	34	3.2	94	41
600	60	7.1	12	2.1	51	3.6	128	46
700	52	6.2	12	1.9	37	2.8	102	45
800	54	5.9	11	1.7	41	3	103	30
SE±	-	1.12	1.4	0.22	6.3	0.39	16.3	8.4
2009/2010 season								
240	50	4	8	2.3	157	5.7	121	59
320	51	6.1	12	3	190	7	153	80
400	55	7.2	13	3.7	223	6.2	189	71
480	62	8.2	13	4.1	277	6.1	222	71
560	63	8.5	13	3.5	223	4.3	192	73
640	62	9.9	16	4.4	300	7.2	221	80
SE±	-	0.7	1	1.08	41.7	0.83	34	10.1

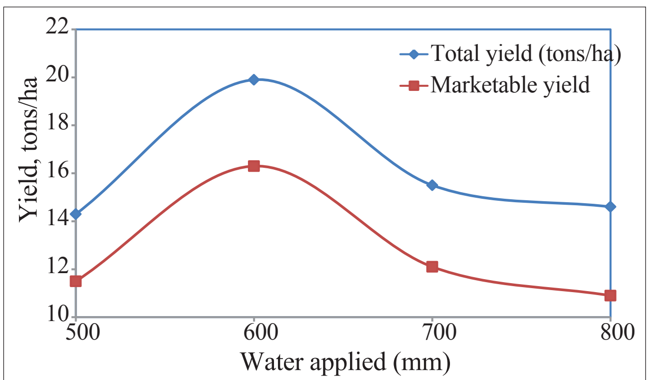

Fig. 1. Effect of applied water on total yields (2008/2009)

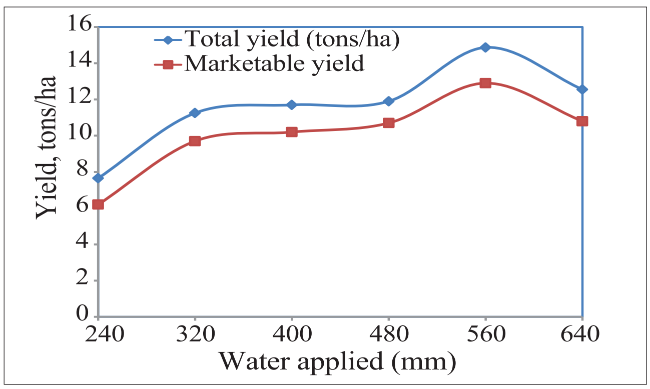

Fig. 2. Effect of applied water on total yields

applied (narrower range than that of the Fs were statistically significant (Figure 2). The highest total yield (14.87 tons/ha) was recorded from the 560 mm water quantity and the lowest from the lowest water applied (240 mm) was 7.65 tons/ha. Total yield in the Ss was lower than in the first for all water applied used. This can be attributed to the short growing period (only 8 irrigations) and to the relatively higher temperature prevailing in the Ss. These findings agreed with those of several studies in different environments, which indicate that the soil moisture deficit in the potato crop leads to a reduction in the total yield (Shock et al., 1992).

There was an increasing trend in total yield in the Ss with increasing water inputs up to 640 mm. The reduction in yield with high water quantity applied (700 and 800 mm) in the Fs could possibly be due to poor aeration of the soil in the experiment site. These results agreed with reports in the literature which indicated that moisture stress, occurring before the onset of tuber initiation and thereafter, effectively reduced the number and weight of tubers (Mackerron and Jefferies, 1986). Moreover, there had been many reports on the effects of water deficiency and irrigation regimes on potato crop in many parts of the world (Ojala et al., 1990; Silva et al., 1990; Kincaid et al., 1993; Fabeiro et al., 2001; Yuan et al., 2003; Onder et al., 2005; Kaur et al., 2005), which show that water deficiency caused a reduction of yield by reducing growth of crop canopy and biomass that may be due to the potato crop had low tolerance for water stress (Patel, 2007; Badr et al., 2012).

Effect of water applied on the qualitative yield components

Effect of watering treatments on the qualitative yield components (Table 4) showed that, the highest marketable yield in the Fs was obtained by applied 600 mm and the lowest yield was associated with the highest water (800 mm) applied due to the increased in the percentage of misshapen and undersized tubers. The results of the Ss indicated a gradually increased in the marketable yield with the water quantities 480, 560 and 640 mm respectively and a decline with lower water quantities 240, 320 and 400 mm. Marketable yield has been reported to be adversely affected by over irrigation (Beukema and van der Zaag, 1990) as well as by water deficiency (lynch and Tai, 1979).

In both seasons, the percentage of infested tubers increased with decreasing amounts of water. As the soil of the experimental site is characterized by high clay content of the montmorillonite type (expanding and shrinking nature), water deficits were expected to cause cracking of the topsoil. Hence, tubers would be exposed to pests and moth which inflicts tuber damage (Ali, 1993).

Evaluation of predicted water requirements of potato crop

The results presented in (Table 5) were indicated that, the calculated seasonal water requirement for the potato crop using Blaney-Criddle method was 491 mm in the first and 451 mm in the second season. While Penman method, it was 524 in the first and 475 mm in the second season. The slight difference between the two methods could be attributed to the

Table 4
Effect of quantity of irrigation water applied on percentage of qualitative yield components in 2008/2009 and 2009/2010 seasons

	Percentage				
Water applied, mm	Infested tubers	Undersized tubers	Misshapen tubers	Green tubers	Marketable yields
2008/2009 season					
500	0.4	7.1	5.1	9.3	78.1
600	0.3	5	3.2	6	85.5
700	0	8.3	6.2	4.8	79.7
800	0	18.5	9.5	4	73
SE±	0.5	1.6	2.11	4.2	21.32
2009/2010 season					
240	4.4	12.1	4.1	4.8	74.6
320	3.2	9.3	1.5	2	84
400	2.5	9.6	1.4	0.3	86.2
480	1.9	6.2	0.8	0	91.1
560	1.7	7.5	1.2	0	89.5
640	0	6.3	1.1	0	92.6
SE±	2.31	4.31	1.9	1.51	18.6

Table 5
Seasonal water requirement of the potato crop using the Blaney-Criddle and Penman methods, 2008/2009 and 2009/2010 seasons

Month	Number of days	Penman, mm		Blaney-Criddle, mm	
		Req/month	Req/day	Req/month	Req/day
2008/2009 season					
November	1	4.7	4.79	4.5	4.5
December	31	127	4.1	127.1	4.1
January	31	160.4	5.18	139.5	4.4
February	28	138.6	4.95	130.2	4.65
March	15	93	6.2	90	6
Total	106	523.7	-	491.3	-
2009/2010 season					
November	14	81.2	5.8	78.4	5.5
December	31	155	5	151.9	4.9
January	31	155	5	144.2	4.7
February	15	84	5.6	76.5	5.1
Total	91	475.2	-	451	-

fact that the Penman method is a function of more meteorological data (temperature, humidity, wind and sunshine duration) and, therefore, is likely to give closer estimate to the crop evapotranspiration and/or to the optimum applied water. These results coincide with the findings provided by Farbrother (1970) on cotton and faba bean in the Gezira scheme, Sudan; who reported that, there were close agreements between the estimated water requirements and the actually applied water for cotton and faba bean. Similarly, water requirement for the optimum production of tomato at “Um Dom” area, Khartoum state, Sudan has been reported by Ibrahim (1984) to be 596 mm/season. The marked difference between the estimated tomato and potato crops water requirement could be explained by the fact that crop evapotranspiration is a function of the crop coefficient, which varies with crop growth habit.

Conclusions

As experimentally evident, the weather conditions, water, soil characteristics and the agronomic techniques affect the crop growth and crop production. Yield components of potato were affected significantly by optimum irrigation treatment. There is a close agreement between the actually applied and the estimated water requirement for the potato crop, on the other hand Blaney-Criddle method could be adopted in the semi-arid environment of Sudan, because it is simple and only required the data on temperature and day length. The optimum amount of water for the best growth, yield and quality of the potato crop at Waramli area environment ranges between 560 and 600 mm/season, to be applied in 8 – 10 irrigations, depending on the prevailing weather conditions.

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