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Effect of Deficit Irrigation at Different Growth Stages on the Yield of Potato

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Abstract: Field experiments were conducted with potato in a silt-loam soil of the Bangladesh Institute of Nuclear Agriculture sub-station farm, Rangpur, Bangladesh during the winter season (November-March) of 1993-94 and 1994-95 to study its yield response due to deficit irrigation imposed at different growth stages. Nine different irrigation treatments were followed with the combinations of four different growth stages (i.e. stolonization, tuberization, bulking and tuber enlargement) allowing water stress at single to all stages. Irrigation showed significant effect on the yield of potato in 1993-94. But there was no significant yield difference due to different levels of watering and stresses of potato during 1994-95. Highest potato yields of 21.0 t/ha and 25.97 t/ha were obtained in 1993-94 and 1994-1995 by applying a total of 7.38 cm and 7.06 cm irrigation water, respectively, at stolonization, tuberization and bulking stages. It was also found that water stress at the early two stages (I. e. stolonization and tuberization) showed sharp negative response to the yield of potato compared with bulking and tuber enlargement stages. Thus, the experimental results revealed that irrigation at tuber enlargement stage could be withheld without significant yield decrease in potato.

Key words: Deficit irrigation, growth stage, evapotranspiration, water use efficiency, potato

Introduction

Irrigation is needed for successful crop production, where stored soil moisture and natural precipitation is not sufficient to meet the crop water demand. Irrigation schedule is usually made for a crop depending on the demand of the crop at different growth stages. It has been established from the research results that irrigation demand of crops vary widely depending on the stage of the crop. Depending on the water availability and water price, irrigation water application can be omitted at certain growth stages of the crops. Imposing field crops to certain water stress may not cause significant yield decrease. The omission of irrigation at certain growth stages (putting under stress) is termed as 'deficit irrigation'. This is an intentional under-irrigation but a useful management technique for increasing net farm income under certain circumstances (English and Nakamura, 1989). Yield reduction in deficit irrigation is minimized through the cost of water savings or yield increase from new command areas out of water savings from deficit irrigation (English, 1990).

Irrigated agriculture provides higher crop yield but the performance of many irrigation projects has fallen short of expectations as a result of inadequate water management at farm and system level. Irrigation scheduling under deficit irrigation scheme may provide an option to increase the effective use of water at farm level in sustaining agricultural productivity under irrigated conditions. Very few researchers (Khan *et al*., 1981; Karim *et al*., 1981-82; Karim *et al*., 1982; Islam *et al*., 1990) have examined the water stress response of field crops, specially for potato. On the other hand, some researchers (Yaron and Bresler, 1983; English and Raja, 1996) reported for modifying irrigation schedules to save water, and thereby improving water use efficiency in irrigation projects Thus, the objective is aimed to identify the most water sensitive growth stages of potato and its yield response due to deficit irrigation at different growth stages. Therefore, irrigation at less sensitive stages could be omitted and used to increase command area in the irrigation project.

Materials and Methods

Site and climatic conditions: The deficit irrigation experiment was carried out on the research farm at Rangpur sub-station of the Bangladesh Institute of Nuclear Agriculture (BINA) during the winter season (November – March) of 1993-94 and 1994-95. The geographical location of the area is 25°45′ N, 89°15′ E at 34 m above MSL. The soil at the farm is classified as deep gray terrace soil of the north eastern barind tract agro-ecological zone of the country. The soil has a bulk density, basic infiltration rate, field capacity, wilting point and pH value of 1.38-1.48 gm cm^{-3}, 0.7 cm hr^{-1} , 42 % by volume, 18 % by volume and 7.0, respectively.

The ten years total annual rainfall at the experimental site is shown in Fig. 1. It shows that the minimum and maximum annual rainfall ranges between 1300.00 to 2800.00 mm, respectively, with an average annual rainfall of 2156.00 mm. The growing season of potato at the experimental site is from November to February, which is the winter period of the country. The growing season rainfall, evaporation, humidity, maximum and minimum temperature and water table fluctuation were recorded and are depicted in Fig. 2.

Field experimental layout and crop husbandry: The experimental design was a randomized complete block with three replicates, having unit plot size of 4 x 5 m^2. Each plot was diked all around and acted as check-basin. Each replicate and individual plot was separated from each other to prevent seepage by providing buffer zone of 0.5 m and 0.3 m wide, respectively, to prevent seepage. Different growth stages of the potato crop were considered as:

Stage I: Stolonization; up to 25 days after sowing (DAS)
Stage II: Tuberization; From 26 to 55 DAS
Stage III: Bulking; From 56 to 65 DAS
Stage IV: Tuber enlargement; From 67 to 85 DAS

Irrigation treatments followed for the study were as stated below:

T_1 (1111); Normal watering at all stages
T_2 (0000); Continuous stress at all stages
T_3 (0111); Single stress at stage I
T_4 (1011); Single stress at stage II
T_5 (1101); Single stress at stage III
T_6 (1110); Single stress at stage IV
T_7 (0011); Two stresses at stages I and II
T_8 (1001); Two stresses at stages II and III
T_9 (1100); Two stresses at stages III and IV

All the above treatments were followed in both the years. But in 1994-95, a slight modification was made in treatment 0000, where the available soil moisture (ASM) when depleted up to 80% at the effective crop root zone, then irrigation water was added to increase the soil moisture up to 50% of the ASM.

Before sowing, each treatment plot was fertilized with basal dose of 250 kg oil cake ha^{-1}, 140 kg N ha^{-1} as urea, 100 kg P_2O_5 ha^{-1} as TSP, 180 kg K_2O ha^{-1} as MP, 2 kg Zn ha^{-1} as zinc oxide and 10 kg S ha^{-1} as gypsum. Dividing the total urea dose into two applications, one half of the urea (70 kg N ha^{-1}) with the other fertilizer was applied at the final land preparation. The rest half of the urea (70 kg N ha^{-1}) was applied as top dressing at stage I. The potato crop was sown at the rate of 235 kg ha^{-1} with the variety "Cardinal" (*Solanum tuberosum*) on third week of November in both the years, maintaining line to line and plant to plant distances of 60 and 30 cm, respectively. The area outside the experimental plots was also sown to provide buffer crop. Then during the whole crop growing period, all other cultural practices were done as and when necessary according to the field and crop conditions. Finally, the crop was harvested on first week of March in both the years, recording yield and different yield attributing parameters as: number of tubers per plant, tuber weight per plant, 1000 tuber yield, tuber and biomass yield. All the data were then analyzed statistically following LSD.

Irrigation calculation and scheduling: At each stage of the crop, irrigation water to be applied was calculated on the basis of crop growth stage using pan evaporation data and crop factor at different stages of the crop. The later was chosen from FAO report (Doorenbos and Pruitt, 1977) and local weather condition. On each plot one aluminum access tube was installed to a depth of 1.2 m prior to sowing. Profile soil moisture was then monitored in every 15 cm increment at sowing, before and 24 hrs after the application of each irrigation, and finally at harvest to check overall profile soil moisture distribution of all the treatment plots. Soil moisture of the top 0-15 cm depth was monitored using gravimetric method. The soil moisture data periodically monitored was also used to check and maintain the scheduled irrigation to replenish the deficit water in treatment 0000 in 1994-95 as explained before. Changes in profile soil moisture content were calculated as (Yule, 1984):

$$\Delta S_m = {}^{n}\sum_{I=1} (\Delta w_i \times \rho_{min} \times Z_{rcf}) / \rho_w \qquad (1)$$

where ΔS_m is the change in soil moisture over the profile considered (cm), Δw_i is the moisture content for a given ith depth in between any two sampling times (cm^3 cm^{-3}), ρ_{min} is the minimum value of the bulk density (gm cm^{-3}), Z_{rcf} is the depth of soil sampling interval (cm), ρ_w is the density of water (gm cm^{-3}) and n is the total number of depth increments in the profile.

The irrigation water requirement for potato was estimated using the following equation as:

$$NIR = CPE \times K_c - R_e \qquad (2)$$

where NIR is the net depth of irrigation water, CPE is the cumulative open pan evaporation from a class-A pan. K_c is the crop factor and it was assumed to be 0.4 for stage I, 0.6 for stage II, 0.8 for stage III and 0.4 for stage IV. R_e is the effective rainfall during the growing season, which is the part of the rainfall that forms a component of the consumptive use. Rainfall < 10 mm was considered as non-effective. An open pan specified by Michael (1978) was installed in the cropped area and the daily evaporation was recorded at early morning. Cumulative evaporation from sowing to first stage and during the next intermediate period of the successive stages were recorded. Net depth of irrigation water was then determined using equation 2. The whole practice was continued up to fifteen days before harvest. The measured amount of irrigation water was applied to the experimental plots using calibrated buckets of known volume from the water intake field channel.

Water use by the crop and water use efficiency: Total accumulated crop water use or evapotranspiration (ET) was calculated from the water balance equation as:

$$ET = I + R_e \pm \Psi_\theta \pm \Delta S_m \qquad (3)$$

where I is the applied irrigation amount, R_e is the effective rainfall, Ψ_θ is the upward flux into the root zone. As water table was more than 2.17 m below the soil surface (Fig. 2) in both the years, so upward flux or crop uptake from the water table by capillary fringe was considered negligible. Moreover, very small amount (< 3.0 cm) of irrigation water was applied in each irrigation application in the treatment plots just to fulfill the scheduled deficit moisture at the crop root zone. So, no surface run-off occurred. Water production function or water use efficiency (WUE) was computed as:

$$WUE = Y / ET \qquad (4)$$

where WUE is the water use efficiency (kg ha^{-1} cm^{-1}) and Y is the fresh fruit yield (kg)

Table 1. Effect of deficit irrigation on the yield and yield components of potato

Treatments	No. of tubers per plant		Wt. of tubers per plant (g)		1000 tubers wt. (kg)		Tubers yield t ha^{-1}		Biomass yield t ha^{-1}	
	1993-94	1994-95	1993-94	1994-95	1993-94	1994-95	1993-94	1994-95	1993-94	1994-95
1111	6	6	342.00	618.3	56.10	95.4	18.83	25.40	2.83	12.72
0000	6	6	242.00	641.3	41.70	110.1	14.50	25.68	2.81	11.93
0111	6	6	241.67	558.0	43.90	99.4	14.83	24.72	3.24	12.63
1011	5	5	296.00	487.0	52.10	97.5	18.58	23.47	2.92	12.39
1101	7	5	341.66	524.6	51.10	113.4	17.75	24.43	3.20	10.99
1110	6	5	333.33	495.6	52.50	102.4	21.00	25.97	2.94	12.36
0011	6	5	254.33	430.6	42.90	82.4	16.17	21.25	3.03	10.76
1001	6	5	292.00	514.3	47.50	92.0	19.00	24.03	2.73	11.24
1100	5	6	300.33	639.3	57.70	108.7	19.08	23.60	3.17	11.96
LSD (0.05)	1.06	0.99	57.26	78.75	0.77	11.6	3.58	NS	0.38	NS

Table 2: Evapotranspiration components and water use efficiency (WUE) of potato under deficit irrigation treatments

Year	Treatments	Applied irrigation water (cm) I	II	III	IV	Total irrigation water (cm)	Rain fall (cm)	Evaporation (cm)	Soil water depletion (cm)	Total crop water use (cm)	Tuber yield t ha^{-1}	WUE t ha^{-1} cm^{-1}
	1111	2.55	2.53	2.30	0.56	7.94			2.98	15.42	18.83	1.22
	0000	0.00	0.00	0.00	0.00	0			1.7	6.2	14.50	2.33
	0111	0.00	2.53	2.30	0.56	5.39			11.51	21.4	14.83	0.69
	1011	2.55	0.00	2.30	0.56	5.41			7.85	17.76	18.58	1.04
1993-94	1101	2.55	2.53	0.00	0056	5.64	4.5	24.9	9.98	20.12	17.75	0.88
	1110	2.55	2.53	2.30	0.00	7.38			2.95	14.83	21.00	1.41
	0011	0.00	0.00	2.30	0.56	2.86			4.13	11.49	16.17	1.40
	1001	2.55	0.00	0.00	0.56	3.11			12.62	20.23	19.00	0.93
	1100	2.55	2.53	0.00	0.00	5.08			5.33	14.91	19.08	1.27
	1111	2.86	2.80	1.40	0.42	7.48			21.1	28.58	25.40	0.88
	0000	0.00	1.78	2.38	0.00	4.16			19.08	23.24	25.68	1.10
	0111	0.00	2.80	1.40	0.42	4.62			11.19	15.81	24.72	1.56
	1011	2.86	0.00	1.40	0.42	4.68			13.03	17.71	23.47	1.32
1994-95	1101	2.86	2.80	0.00	0.42	6.08	0.0	20.8	10.18	16.26	24.43	1.50
	1110	2.86	2.80	1.40	0.00	7.06			21.05	28.11	25.97	0.92
	0011	0.00	0.00	1.40	0.42	1.82			18.83	20.65	21.25	1.02
	1001	2.86	0.00	0.00	0.42	3.28			20.25	23.53	24.03	1.02
	1100	2.86	2.80	0.00	0.00	5.66			15.01	20.67	23.60	1.14

Fig. 1: Total annual rainfall (1988-97) of the experimental area.

Fig. 2: Some growing season climatological data of the experimental area.

Fig. 3: Profile soil moisture distribution under different deficit irrigation treatments in 1993-94

Fig. 4: Profile soil moisture distribution under different deficit irrigation treatments in 1994-95

Results and Discussion

Climatological parameters: Some growing season climatological data are depicted in Fig. 2. It indicated that in 1993-94, small amount of rainfall (about 45 mm) occurred at the middle and later part of the crop growing period (50-70 DAS) during the tuberization, bulking and tuber enlargement stages. Whereas in 1994-95, during the whole experimental period rainfall was almost nil (< 1 mm). The 10 years (1988-97) annual total rainfall in the experimental area (Fig. 1) represents to be quite sufficient and varies considerably from year to year with a range of highest 2811 mm in 1995 to a minimum of 1301 mm in 1994. The distribution of the precipitation indicated that the growing season of potato (November-March) was characteristically dry with minimum rainfall and most of the precipitation concentrated beyond this period. Evaporation was almost the same showing a little higher value in 1993-94 (total 249 mm) than in 1994-95 (total 208 mm), exceeding the total rainfall of both the years. It was also evidenced that during the experiment evaporation (10 days total) was around 20 mm in the no rainfall period and increased thereafter but hardly exceeded 35 mm at the later part of the crop growing period in 1993-94. In 1994-95 initially evaporation was higher and afterwards it was very much fluctuating throughout the entire growing season. The maximum humidity (10 days average) in both the years was more than 93% and the minimum was about 40 to 60% throughout the experimental period. Minimum and maximum temperature (10 days average) ranged from 8 to 30 °C. Hence from the available data, the experimental area in the growing season was also characterized by high humidity and moderately cold with a dry spell.

Spatial distribution and dynamics of soil water: Fig. 3 and 4 show the profile soil moisture distribution of the deficit irrigation treatment plots at different times during the experimental period. Water stress of crop depends on the rainfall and its distribution during the growing season as well as on the stored profile soil moisture. The crop yield is also directly affected by the spatial distribution of soil water content (Li, 1998). The sowing time soil moisture in different treatment plots ranged from 13 to 47% in 1993-94 and 23.5 to 48.4% in 1994-95 (by volume) at 15 to 120 cm soil depth. Later on with the advance of the crop growing period, water demand of the crop increased and the extractable profile soil moisture was rapidly depleting through evapotranspiration and continued till the application of supplemental irrigation water where plants were subjected to water stress. It was also evidenced that by irrigation application at different predecided stages, soil moisture was increased and then it gradually decreased up to the following irrigation time. As a result soil profiles dried up by loosing their water in the intermediate period and it again gained water in the next irrigation. Wetting and drying phenomenon of irrigation on unsaturated soil was also reported by different researchers elsewhere (Corbeels *et al*., 1998; Cooper and Gregory, 1987; Van den Boogaard *et al*., 1996). In 1993-94, harvest time soil moisture was higher in all stage stress treatment plots as there was rainfall during the later part of the crop growing period. But in 1994-95, the harvest time soil moisture drastically reduced as there was no rainfall during the whole crop growing period.

Irrigation frequency and soil water depletion: As irrigation was applied at four different stages only, the maximum number of irrigation was four in treatment 1111 and minimum zero in all stages stress treatment plots. Thus, irrigation amount also varied from 7.94 cm (in all stages irrigated plots) in treatment 1111 to zero (in all stages stressed plots) in treatment 0000 in 1993-94, and almost the same amount of water was applied in 1994-95 (Table 2). It also clearly indicated that irrigation amount increased at later stages compared with the earlier stages as evaporation rate increased at the later part. Pattern of soil water depletion showed that the highest depletion occurred in treatment 1001 in 1993-94 and in treatment 1110 in 1994-95, amounting to 12.62 cm and 21.05 cm, respectively (Table 2). The reason might be that in the irrigated plots, there the crop had the greater opportunities for abstracting more water from the excess readily available water in soil compared with less or non-irrigated plots. It was also remarkable that the trend of soil moisture depletion was higher when irrigation was made in the middle two stages (I. e. stage II and stage III) rather than the first and final (I. e. stage I and stage IV) stages. Observations also indicated that irrigation at stage II and stage III, the crop was more effective in utilizing stored soil moisture than irrigation at stage I (Fig. 3 and 4). It thus showed the lowest profile soil moisture in 15 to 60 cm soil depth than the deeper layers (> 60 to 120 cm). This could be that at these stages demand of water of the actively growing crops increased and extracted the soil moisture by the network of effective roots spreading at this depth. Similar explanations were also given by Corbeels *et al*. (1998). In contrast, at stage IV, there the crop already reached at its final and mature stage with less evaporation demand and crop water uptake by root was retarded, consequently declining the rate of soil moisture depletion pattern and showed the higher profile soil moisture.

Effect of deficit irrigation on the yield of potato: Yield and yield attributing characters of potato as affected by different deficit irrigation treatments are presented in Table 1. It showed that deficit irrigation had significant effect on yield in 1993-94 and did not have any influence on it in 1994-95. Amongst all the treatment combinations, water deficit imposed at stage IV (I. e. tuber enlargement stage) in treatment 1110 produced the highest potato yield of 21.00 t ha^{-1} and 25.97 t ha^{-1} in 1993-94 and 1994-95, respectively. In comparison with that when stress was imposed at the last two stages I. e. stage III and stage IV (I. e. bulking and tuber enlargement stages) in treatment 1100 and, yields were insignificantly reduced (about 10%) in both the years. Also when irrigation was withheld at early stages (I. e. stage I and stage II) of treatment 0111 and 1011, yields were reduced to 41.60% and 13.02% respectively, in 1993-94 and less than 10% in 1994-95, compared with treatment 1110. In addition to that when stress imposed at stage II and stage III of treatments 1011 and 1101, yield response showed declining rate. Thus, it was evidenced that water deficit at vegetative and maturity stages (I. e stage I to stage III) pronounces sharp response to the yield of potato. It was also remarkable that yield of potato in 1993-94 was reasonably low compared to 1994-95, and irrigation response was very much distinct. The reason might be due to high residual soil moisture at sowing time in 1994-95 than in 1993-94. In contrast to that in 1994-95, without rainfall but having adequate soil moisture the crop showed better performance than in 1993-94. It also postulates that early stage irrigation is very much essential for potential yield of potato, and irrigation delaying at stage III up to the stage IV or even withdrawing irrigation at these stages will have no considerable impact on yield reduction. In contrast to that when continuous irrigation was applied in all stages in treatment 1111, yield was not increased, rather decreased comparing with treatment 1110 by imposing water stress at stage IV. Steiweek (1958) reported that stolonization (stage I) and tuberization (stage II) are the most water sensitive stages of potato crop. He further added that sufficient moisture at the bulking is also necessary for the proper development of tubers. It was also found that in 1993-94, when continuous stress was imposed in all the stages in treatment 0000, yield was drastically reduced producing the lowest yield of 14.50 t/ha^{-1} compared to any irrigation

treatment. In 1994-95 when this treatment was practiced to supplement with irrigation up to 50% of the 80% depleted ASM, yield was increased in comparison with the continuous watering at all stages in treatment 1111. Here it pleads that too much irrigation is also detrimental for the potato crop.
Therefore, experiencing from the above facts it is quite justifiable to guess that with the prevailing irrigation and soil moisture condition in treatment 1110, the potato crop produced bumper yield compared to the national average potato yield of 10.94 kg ha^{-1} (BBS, 1995). From the experimental results, it was evidenced that irrigation has pronounced effect on the yield and yield components of potato. It also shows that early three stages (I. e. stage I, stage II, and stage III) are very much responsive to irrigation than the late stage (I. e. stage IV) and irrigation in this stage does not bring any beneficial effect to the crop yield. Hence, it may be practiced to apply irrigation at stages I, II and III for the highest output under abundant water availability. In case of deficit or water scarcity irrigation may be practiced at stage I and stage II for higher yield of potato. Here it can be interpreted that water deficit during the vegetative stage indicates also to be harmful than those in the other stages. Yield components studied viz. number of tubers per plant, weight of tubers per plant and 1000 tuber yield showed significant treatment differences in both the years which accordingly contributed to the tuber yield. For the treatment 1111 in 1993-94, all the yield parameters were increased but for no obvious reasons the tuber yield was lower (non-significantly) than in treatments 1110, 1001 and 1100. Mean biomass yield was significantly affected by different treatments in 1993-94, whereas no significant difference was found in 1994-95 and yield was almost the same. Nevertheless, in both the cases the highest biomass yield was recorded in treatment 0111.

Water use under different deficit irrigation treatments: Irrigation amount was naturally high for all stages watering (in treatment 1111) in both the years (Table 2). It was observed that depending on the rainfall distribution, soil water depletion inconsistently varied in 1993-94 reflecting it to the amount of total crop water use and the highest crop water use was recorded in treatment 0111 (21.4 cm), narrowly followed by treatments 1001 and 1101 (around 20 cm each). The highest seasonal crop water use in 1994-95 was recorded in treatments 1111 and 1110 (about 28 cm each), closely followed by treatments 0000, 1001 and 0011 (20 to 23 cm). But the highest yields of potato (21 t ha^{-1} and 25.97 t ha^{-1}) were recorded in treatment 1110 in 1993-94 and 1994-95 with a corresponding total crop water use of 14.83 cm and 28.11 cm. In an experiment with some potato variety, the "Cardinal" variety recorded a yield of 22.3 t ha^{-1} using 26.7 cm total water (Islam *et al.*, 1990).
Therefore, from the experimental findings it was clear that the potato crop needs supplemental irrigation. Under the experimental condition it was also found that the early two stages (stolonization and tuberization) are very sensitive to water stress compared with the later two stages (Bulking and tuber enlargement stages). Thus, for getting optimum yield of potato and economic use of water, irrigation could be ignored at tuber enlargement stage and in case of more water scarcity, even at bulking stage also without significant decrease in potato yield.

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