Influence of deficit irrigation and nitrogen fertilization on potato yield, water productivity and net profit

Adel H. Elmetwalli[1*] and Moataz K. Elnemr[2]

(1. Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, Egypt;
2. Department of Agricultural Engineering, Faculty of Agriculture, Damietta University, Egypt)

Abstract: Potato is described as a sensitive crop to short periods of irrigation deficit and Nitrogen deficiency. Farmers usually use excessive amounts of irrigation water and fertilizers to obtain higher yields. A field experiment was undertaken to assess the effects of irrigation regime and Nitrogen fertilization on potato tuber yield, Chlorophyll content and irrigation water productivity. Four levels of applied water 1.25, 1.00, 0.75 and 0.50 of the crop evapotranspiration (ETc) were examined with three amounts of Nitrogen (N) 50, 125, and 200 kg ha^{-1}. The results demonstrated a significant influence of both factors on potato yield. The highest potato yield of 29.3 Mg ha^{-1} was obtained with the treatment 1.25 ETc and 200 kg N ha^{-1}. Water productivity was conversely proportioned with an increasing amount of applied water since the highest average record of 27.2 kg m^{-3} obtained with the lowest amount of applied water. Net profits followed the trend of tubers production and they were decreased by decreasing both amount of applied water and Nitrogen. Consequently, the results recommended that, potato can be grown with acceptable potato yield and quality while saving water and using Nitrogen fertilization more efficiently

Keywords: deficit, fertilization, net profit, potato, sprinkler irrigation, water productivity, Egypt.

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1 Introduction

There is a growing global awareness of the increased demand for good quality water resources, particularly in arid and semi-arid regions. Despite the massive efforts made by governments, there is still a serious water problem due to the continuous increase of water demands especially for the agricultural sector. Low water application efficiency of irrigation systems at the field level must be optimized through modern irrigation systems such as drip and sprinkler irrigation systems which can apply higher water productivity by decreasing differnt water losses such as runoff, deep percolation, and evaporation from soil surface. Potato (Solanum tubersum) is one of the most consumed vegetables in human food around the world, even It may even be considered a strategic crop in some countries.

Potatoes occupy an average area of about one million hectares, which produces about 18 million tons of potato tubers (FAO, 2008). It can be planted in different soil types and climatic environments. In the Mediterranean region, irrigation represents an important factor in early potato cultivation. Water and Nitrogen were considered the most important factors affecting potato yield and quality through affecting potato tuber growth, development and quality. Understanding the separated effects of water and Nitrogen

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***Corresponding author: Adel H. Elmetwalli,** Associate Professor, Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, Egypt. Tel: +201001737233. Email: Adel.elmetwalli@agr.tanta.edu.eg.

management is important for obtaining higher yield and quality. However, the interaction between these two factors is also recognized as an important issue towards accomplishing optimum yield and quality and decreasing energy costs.

Basically, water deficiency is a common adverse factor for field crops (Wu et al., 2008). Proper irrigation scheduling over the growing season could enhance potato productivity (Panigrahi et al., 2001). Applying less watering regime during tuber initiation decreased the number of tubers per plant (Cappaert et al.,1992) and tuber size and specific gravity were significantly reduced by water stress during this growth stage. Subjecting plants to long periods of severe water stress could delay the growth of plants and therefore caused changes to the morphological structure and the distribution pattern of biomass (Wegener and Jansen, 2013). Applying the optimum level of irrigation regime to potatoes is crucial to using water more efficiently since excessive irrigation decreases yield while insufficient irrigation results in water stress and decreases potato yield (Wang et al., 2006). Thus, identifying accurate evapotranspiration is fundamentally important for optimal irrigation scheduling. Ierna et al. (2011) studied the interaction of water and Nitrogen fertilizer on potato under different irrigation methods and noticed a marked interaction between the irrigation regime and fertilization rate on potato tuber yield, irrigation water productivity and fertilization productivity. King et al. (2003) investigated the effect of irrigation rate (60% and 80% ET_c) on potato tuber yield (var. Russet Burbank) and concluded that the total yield of potato decreased fundamentally when deficit irrigation was applied during early mid and mid late bulking. Patel and Rajput (2007) assessed the effect of drip line depth (5, 10, 15, and 20 cm) and watering level (100%, 80% and 60% ET_c) on potato yield and concluded that potato yield decreased with decreasing the amount of irrigation water. Potatoes are basically sensitive to the stress of Nitrogen and even to its deficiency, as a result of its shallow roots, high demand of nutrients and inefficient rooting system, potatoes are in need for high amounts of fertilizer (Pack et al., 2006). The influence of Nitrogen fertilization on potato productivity has been quantified by many previous researchers. For example, Yang et al. (2017) suggested that the potato could be planted with a moderate proportion of wetted soil volume (40%-50%) and a medium level of applied Nitrogen (135-150 kg N ha^{-1}) under drip irrigation with mulch producing decent yields and qualities while saving irrigation water and conserving Nitrogen fertilizer. Zvomuya et al. (2003) concluded that the Nitrogen deficiency could substantially reduce potato yield, whereas excessive N application could delay tuber maturity and increase the nitrate contamination of surface and groundwater. Fouda et al. (2012) studied the effect of deficit irrigation and Nitrogen fertilizers on potato yield and found that increasing amount of applied water and Nitrogen amount will lead to increase the crop yield. El Mokh et al. (2015) investigated the effect of irrigation regime and Nitrogen fertilization on potato yield and water productivity and found that water deficit had more effects on potato yield and water productivity than N application. Tolessa et al. (2016) quantified the influence of watering regime and Nitrogen fertilization on potato water use efficiency (WUE) and found that watering regime significantly affected WUE while Nitrogen showed no significant effects on WUE.

Proper and effective irrigation scheduling and efficient fertilization management are among the possible useful options to increase the water productivity particularly when water resources are scarce. Moreover, efficient management of Nitrogen fertilization is important when the cost is considered. Therefore, the optimum application of both Nitrogen fertilization and water are required for better potato growing, regular growth, and marketable tubers. The overall aim of this research was to investigate the response of the potato crop to both watering and Nitrogen fertilization levels under sprinkler irrigation.

2 Materials and methods

2.1 Agronomic practices

To achieve the overall aim of this research, a field experiment of potato was undertaken at a private farm (30º 36\ N, 30º 37\ E), Elnobaria region, Bohaira province during the spring season of 2016. Potato tubers (spunta variety) were planted on 21st March 2016. Two soil samples were sampled at different soil depths (15-30cm and 30-60 cm) for chemical and mechanical analysis. The soil of the experimental study site was sandy loam with typical particle size distribution of 65.2% sand, 27.6% silt and 7.2% clay. Table 1 details the chemical analysis of the experimental soil for two successive soil layers; 0-30 and 30-60 cm). The electrical conductivity of the soil and bulk density were 1.24 dS m^{-1} and 1.35 g cm^{-3}, respectively.

Table 1 Different chemical and physical properties of the experimental soil

Depth (cm)	EC ($dS\ m^{-1}$)	pH	Cations ($meq\ L^{-1}$)				Anions ($meq\ L^{-1}$)				Texture
			Ca	Mg	Na	K	Co_3	HCO_3	Cl	SO_4	
0-30	1.24	7.44	3.79	2.13	5.11	1.43	0.0	3.38	7.12	1.96	Sandy loam
30-60	1.26	7.29	4.12	2.22	4.98	1.31	0.0	3.27	6.88	2.48	Sandy Loam

Tubers were planted in rows of 0.50 m spacing and 0.40 m between plants. One meter distance was left between different treatments as a buffere zone to avoid overlapping between different treatments. Phosphorous was applied in the form $Ca(H_2PO_4)$, $2CaSO_4$ which is commercially known as super Phosphate. Potassium was applied during soil preparation at a rate of 60 kg ha^{-1} each. Nitrogen fertilizer was added in the form of NH_4NO_3 and applied in two equal doses; the first one at 35 days after planting and the other at 55 days after planting. Weeding was performed manually over the growing season.

2.2 Experimental design and variables

The experiment layout of this research was set up as a split plot design with three replicates. Irrigation treatments were allocated to the main plots and Nitrogen fertilization rates were allocated to the sub-plots. Different levels of watering and Nitrogen deficiency stress comprising 12 various treatments including: four watering levels, which are 1.25, 1.00, 0.75 and 0.50 of ET_c and three N rates of 50, 125 and 200 kg ha^{-1} were used. Statistical analysis system (SAS) package was employed for the statistical analysis of the data. Data were checked for normality using the Anderson-Darling method with a 95% significance level. Differences between various treatments were checked through Duncan's multiple range test at 5% probability level. MSTAT software was used to perform the mean comparison for the values of potato tubers productivity.

2.3 Irrigation system layout and calculation of crop water requirements

Fixed sprinkler irrigation system, consisted of a centrifugal pump operated by an electrical engine was employed for the experiment. A 10 cm (4 inch) diameter mainline made of steel was buried under the soil surface. The sub-main and lateral lines of 7.6 cm (3 inch) and 5 cm (2 inch) diameter respectively were installed on the soil surface. Valves were fitted on the submains to control the distribution of water on laterals. Rain Bird 20JH impact sprinklers with a discharge rate of 750 L h^{-1} were mounted on 0.75 m high riser. The sprinklers were fitted on the lateral lines at 12 m spacing and the distance between laterals was 12 m (square layout). The sprinkler system was operated at a pressure of 250 kPa.

Averages of required climatic data obtained from Albostan meteorological station (30º 47\ N, 30º 28\ E) for the period 2005-2015 were used to calculate crop water requirements. Irrigation water requirements were based on the calculation of potential evapotranspiration using FAO Penman-Monteith equation modified by Allen et al. (1998) as follows:

$$ET_c = ET_0.K_c \tag{1}$$

Where:

ET_c : irrigation water requirements, mm day^{-1}

ET_o : reference evapotranspiration, mm day^{-1}

K_c: potato crop coefficient.

FAO method was employed to quantify crop coefficient (FAO, 1998). Potato growing season in this method is divided into four growth stages and depending on the environmental conditions of the study area. The crop coefficient was taken as 0.55, 0.65, 0.85 and 1.10 for the primary, mid, bulking and final stage respectively.

2.4 Measurements

2.4.1 Chlorophyll content

Six leaves from each replicate were used to measure the chlorophyll content. Measurement has been taken place using Konica Minolta SPAD-502Plus (Süß et al., 2015).

2.4.2 Crop yield and water productivity

Water productivity is defined as the weight of grains produced from one cubic meter of water and can be calculated according to Rodrigues and Pereira (2009) as follows:

$$P = \frac{Y}{D} \quad (2)$$

Where P is water productivity in Mg m^{-3} of water, Y is the total yield per hectare in Mg ha^{-1}, D is the amount of water applied in m^3 ha^{-1}. The crop reached the physiological maturation after 95 days from planting date at which plant leaves turned into yellow and dried. The average of replicates crop production was used to describe the crop yield of each treatment.

2.4.3 Cost analysis

The net return of any agricultural production is fundamentally important for countries suffering limited natural resources especially water resources. Inputs and net return of various irrigation treatments were investigated to choose the optimum and efficient irrigation method. The total cost of different irrigation treatment was calculated taking into account the rent of water pumping machine (7 hp).

2.4.4 Benefit-cost ratio

Benefit-cost ratio (B/C) is commonly used as an indicator of the return of each dollar invested and is dependent on the net profit and total cost that can be quantified as follows:

$$(B/C) = \text{net profit / total cost} \quad (3)$$

Where net profit is the difference between total cost and total income of the crop.

3 Results

3.1 Chlorophyll content of potato

Figure 1 demonstrates the effects of the watering regime and N fertilization levels on the chlorophyll content of the potato. Broadly, chlorophyll content markedly decreased with the increasing the water Nitrogen deficiency stress. The results clearly demonstrated a significant effect of both N fertilization rate and water deficit on potato chlorophyll concentration. The highest chlorophyll concentration of 47.9 was recorded with the treatment received the highest levels of watering regime and Nitrogen fertilizer (1.25 ET_c and 200 kg N) whereas the lowest chlorophyll concentration of 34.3 was found in the plots irrigated with 0.50 ET_c and fertilized at 0 kg Nitrogen rate.

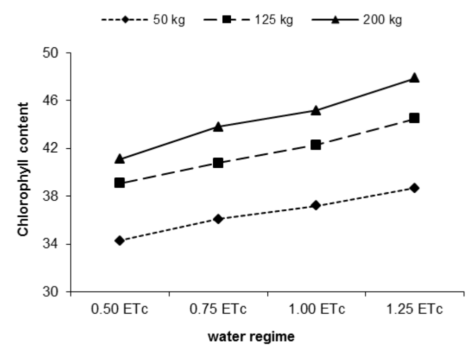

Figure 1 Relationship between both watering regime and Nitrogen fertilization levels and the chlorophyll content of potato crop

3.2 Potato tuber yield

The analysis of variance in Table 2 showed that both Nitrogen level and water regime affected the potato yield significantly. The interaction between the two factors had also a highly significant effect on the potato tuber yields. This significance is due to the sensitivity of potato for the deficiency in both Nitrogen and amounts of applied water (Yuan et al., 2003; Kaur et al., 2005). This is due to the high demand for water and nutrients with its inefficient root zone (Ojaja et al., 1990).

Table 2 Analysis of variance for the effect of experimental variables on potato production

Source	D.F	Sum of squares	Mean square	F value
Replicates	2	4.88	2.44	1.12
Irrigation regime(A)	3	352.91	117.64	53.36**
Error	6	13.23	2.21	
Fertilization rate(B)	2	301.83	150.92	98.42**
A*B	6	60.17	10.03	6.54**
Error	16	24.54	1.53	
	35	757.54		

It is obvious from the results detailed in Table 3, that both Nitrogen deficiency and moisture remarkably influenced potato tuber yield. It can be seen that water deficiency significantly reduced tuber yield since the highest potato yield of 29.28 Mg ha^{-1} was recorded with the treatment receiving 1.25 ET_c. These results are in agreement with the study of (Cappaert et al.,1992) that fully irrigated treatments produced higher potato yield. Full irrigation regimes produced larger potato yield under various levels of Nitrogen fertilization. There were reductions in tuber yield when fewer amounts of irrigation water were applied. The other combinations produced less potato tuber yield and the lowest tuber yield of 15.07 Mg ha^{-1} was recorded with the treatment received 50 kg N and 0.50 ET_c. Applying 25% less water decreased potato tuber yield at all levels of N fertilization. Applying 50 ET_c, that resulted in decreasing potato yield by 21%, 30.6%, and 39.8% at 0, 125 and 200 kg ha^{-1} respectively.

Significant decreases in potato tuber yield were observed with increasing Nitrogen deficiency levels (Table 3).

Table 3 Effect of both water and Nitrogen deficiency on potato tuber yield (Mg ha^{-1})

Irrigation regime	N fertilization rate			Mean
	50	125	200	
1.25 ET_c	19.95DE	23.87BC	29.28 A	24.37
1.00 ET_c	19.15EF	23.07BC	28.38 A	23.54
0.75 ET_c	16.86G	21.98CD	24.67 B	21.19
0.50 ET_c	15.07G	16.83G	17.06 FG	16.32
Mean	17.76	21.43	24.87	

Note: L.S.D= 2.143

The tuber yield fell to about 48.6% of the maximum value for potato when subjected to the lowest watering regime and the highest Nitrogen deficiency level. Nitrogen deficiency reduces canopy growth size and usually causes premature senescence which will lead to less potato tuber yield (Biemond and Vos, 1992). The increase in potato tuber yield may have been a result of improved growth and higher yield components due to higher Nitrogen rates. The results further showed a significant effect of the interaction between Nitrogen fertilization rate and irrigation regime demonstrating that both parameters did not have separate effects. Moreover, in case of increasing the level of water stress, Nitrogen rate was not efficient to produce higher significant yields which may be attributed to the adverse effect of N application rate on the potato crop. These results were obtained by others (Darwish et al., 2003) who stated that under severe water stress conditions, the productivity of potato decreased with higher Nitrogen rates.

3.3 Water productivity of potato

Water productivity (WP) was calculated based on the total fresh potato tuber production for each treatment. It is identified as the ratio between tuber yield at harvest time and water applied. The obtained WP values were significantly influenced by both the irrigation regime and N rates. The results listed in Table 4 demonstrated that water was more efficient in producing higher WP values in the treatments receiving less water (50 ET_c). The highest WP of 28.5 kg m^{-3} was recorded with the treatment received the lowest levels of watering regime and the greatest Nitrogen fertilization rate (0.50 ET_c and 200 kg Nitrogen) whilst the minimum WP of 13.3 kg m^{-3} was recorded with the treatment received the greatest level of watering regime and the lowest Nitrogen fertilization rate (1.25 ET_c and 0 kg N). Increasing Nitrogen fertilization from 0 kg N to 200 kg N increased WP by 26.2% as a result of increasing potato tuber yield.

Table 4 Water productivity of potato crop (kg m^{-3})

Irrigation regime	N fertilization rate			Mean
	50	125	200	
1.25 ET_c	13.30	15.91	19.53	16.24
1.00 ET_c	15.95	19.23	23.67	19.61
0.75 ET_c	18.78	24.42	27.44	23.54
0.05 ET_c	25.11	28.00	28.50	27.20
Mean	18.28	21.89	24.78	

3.4 Economic evaluation

Production costs of potato were quantified taking into account all agronomic practices including ploughing, fertilizers, labour, irrigation cost, pesticides, and tubers. Table 5 details the economical evaluation of potato production costs. The results were evaluated from the economical point of view considering production cost and investment. It is obvious from the results detailed in Table 3 that applying greater amounts of N and watering regime increased the total cost, but resulted in a higher tuber yield and therefore higher total income and thus higher net profit and benefit- cost ratio. The treatment receiving 1.25 ET_c and 200 kg N ha^{-1} produced the highest tuber yield, total income, net profit and B/C ratio (29.3 Mg ha^{-1}, \$3256, \$1504 ha^{-1} and 0.86 respectively) whilst the lowest values were recorded with the treatment received 0.5 ET_c and 50 kg N ha^{-1}(15.07 Mg ha^{-1}, \$1674, \$ 152 ha^{-1} and 0.10 respectively). Among various treatments, 1.00 ET_c produced the second highest total tuber yield and therefore the second highest total income, net profit and B/C ratio. The results demonstrated that applying 0.25 less water with the same rate of N fertilization for the first and second watering regime (1.25 and 1.00 ET_c) decreased the total tuber yield by 3% which was non-significant while saving 25% of irrigation water. The results further showed that increasing moisture stress level to 0.75 ET_c increased tuber yield loss since reducing watering regime from 1.00 ET_c to 0.75 ET_c decreased potato tuber yield by 13% with the same N fertilization rate. In conclusion, choosing the proper irrigation scheduling and fertilization management can enhance potato yield and therefore various economic indicators including total income, net profit and benefit-cost ratio.

Table 5 Economic analysis and net profits of potato yield as affected by irrigation regime and Nitrogen fertilization

Inputs and outputs	Cost, \$ ha^{-1}	Treatment											
		W_1N_1	W_1N_2	W_1N_3	W_2N_1	W_2N_2	W_2N_3	W_3N_1	W_3N_2	W_3N_3	W_4N_1	W_4N_2	W_4N_3
Inputs	Land rent	460	460	460	460	460	460	460	460	460	460	460	460
	ploughing	60	60	60	60	60	60	60	60	60	60	60	60
	tuber price	660	660	660	660	660	660	660	660	660	660	660	660
	Fertilization	38	97	155	38	97	155	38	97	155	38	97	155
	Pesticides	90	90	90	90	90	90	90	90	90	90	90	90
	Labor	84	84	84	84	84	84	84	84	84	84	84	84
	Irrigation cost	188	188	188	150	150	150	113	113	113	75	75	75
	Harvesting	55	55	55	55	55	55	55	55	55	55	55	55
	Total cost	1635	1694	1752	1597	1656	1714	1560	1619	1677	1522	1581	1639
Outputs	Tuber yield, Mg ha^{-1}	19.95	23.87	29.30	19.15	23.07	28.40	16.90	21.98	24.70	15.07	16.08	17.10
	Total income, \$ ha^{-1}	2217	2652	3256	2128	2563	3156	1878	2442	2744	1674	1787	1900
	Net profit, \$ ha^{-1}	582	958	1504	531	907	1442	318	823	1067	152	206	261
	Benefit cost ratio	0.36	0.57	0.86	0.33	0.55	0.84	0.20	0.51	0.64	0.10	0.13	0.16

Note: W_1: 1.25 ET_c, W_2: 1.0 ET_c; W_3: 0.75 ET_c; W_1: 0.50 ET_c , N_1 : 50 kg Nitrogen; N_2 : 125 kg Nitrogen; N_3 : 200 kg Nitrogen

4 Discussions

The objective of this study was to investigate the response of potato yield to the changes in applied water and Nitrogen fertilizers levels. Results of potato yield and chlorophyll content were in agreement with the results obtained by Fouda et al. (2012). Chlorophyl content in leaves showed that the content will be decreased by decreasing both applied water and Nitrogen. Due to this result, crop production has followed the same trend as Chlorophyl content indicates how the plant is able to convert carbon dioxide into oxygen and glucose which are essential for tubers production. Tubers production increased by increasing amount of applied water and Nitrogen. Water regime and amount of Nitrogen had highly significantly affect the potato tubers production. Treatment W_3N_3 showed higher potato production if compared to W_2N_2 despite the less amount of applied water. This result shows that the increase in Nitrogen level can make up the water shortage which was clarified by the statistical analysis which showed the highly significant interaction between the two variables. Water productivity had reached the greatest values at 0.5 ET_c treatments followed by 0.75 $ET_{c.}$ This is due to the less amounts of used water despite the lower production. Net profits followed the trend of tubers production and they were decreased by decreasing both amount of applied water and Nitrogen. Potato is considered highly sensitive crop to both water stress and Nitrogen level. The results of this study showed that increasing amount of apllied water and Nitrogen had been reflected on crop production and net profits. Thus the future studies on these factors should consider the economic benefits of these increase because the expected increase in crop production may considered unprofitable for some other crops due to the increase in production cost.

5 Conclusions

This study aimed to quantify the effects of water deficit and N fertilization deficiency on potato tuber yield, water productivity, biophysical and biochemical properties of the potato crop. Potato tuber yield, and chlorophyll content were significantly affected by the deficiency of both stressors. Water productivity had the opposite trend as it decreased with increasing the amount of irrigation level. Higher Nitrogen fertilization rates increased both tuber yield and chlorophyll content of the potato. The highest yield and chlorophyll content of 29.3 Mg ha^{-1} and 47.9 respectively, were obtained with 1.25 ET_c watering regime and 200 kg N treatment. Moreover, potato productivity can be maximized if the proper irrigation system, optimum water regime and Nitrogen fertilization rate are identified.

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