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Water and Fertilizer Use Efficiency as Affected by Irrigation Methods

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Abstract: Field experiments were carried out in two sites, Shalaqan and Bahteem, Qalubia Governorate. Onion (*Allium cepa* L., Giza 20) and potato (*Solanum tubersum*, Sponta holand) were grown in the 2nd site while, peas (*Pisum sativum*, Master B-short) and onion in 1st site. The investigated soils in both sites are clay loam. Different irrigation methods were used as follows: Un-controlled Surface (UCSI), Controlled Surface (CSI), Surface Drip (SDI) and Subsurface-drip (SSDI). The main objective of this paper is to study the effect of irrigation methods on the use efficiency of both water (WUE) and soil applied fertilizers (FUE). WUE in $kg_y\ m^{-3}$ varied from 6.45 (SDI) to 10.37 (CSI) and from 2.47 (SSDI) to 5.08 (CSI) for onion and peas crop, respectively at Bahteem site. At Shalaqan site, data indicate that UCSI has the maximum value of WUE, while CSI has the lowest one 10.2 and 4.96 $kg_y\ m^{-3}$ irrigation water, respectively for onion crop. The maximum and minimum values of WUE for potato were 3.12 and 0.9 $kg_y m^{-3}$ irrigation water under UCSI and SSDI, respectively. Also, data show that there were significant differences between irrigation methods used in Bahteem and Shalaqan sites except between UCSI (3.12) and SDI (2.04) in last one. The FUE by onion crop at Bahteem, varies in the ranges: from 111.30-171.17, 158.44-243.68 and 163.56-251.54 kg yield kg^{-1} of fertilizers used, according to irrigation methods for N, P_2O_5 and K_2O fertilizers, respectively. In case of peas crop, at the same site, FUE values varied 50.44-90.34, 66.71-119.48; 43.08-77.70 kg yield kg^{-1} of the fertilizers used in the same sequence mentioned before. According to irrigation methods used, FUE values varied from 88.49-168.59, 130.04-247.74 and 125.97-240.00 kg yield kg^{-1} of the fertilizers used in the case of N, P_2O_5, K_2O fertilizers used, respectively (onion at Shalaqan site), but (potato crop) they varied 26.34-60.33, 52.26-119.68 and 33.75-77.23 kg yield kg^{-1} of fertilizers used under SSDI and UCSI irrigation methods and in the case of N, P_2O_5, K_2O fertilizers, respectively. Results revealed that the FUE by onion crop at Bahteem site exceeded that at Shalaqan site. Simple correlation coefficients were calculated between WUE and FUE of N, P_2O_5 and K_2O used. The obtained results reveal that increasing WUE was associated with increasing FUE.

Key words: Irrigation methods · water use efficiency · fertilizer use efficiency · onion · potato · peas

INTRODUCTION

Nowadays the total annual available water resources of Egypt is about 67.27 billion m^3 [1]. The agricultural sector consumes almost 90% of the total allocated water to Egypt. The ever increasing of the Egyptian population and the limited water resources led to a steady decrease in per capita share of water.

Tilman *et al*. [2] stated that the global use of N and P fertilizers increased 7 and 3-5 fold, respectively between 1960 and 1995. They added that both N and P are expected to increase another 3 fold by 2050 unless there is a substantial increase in fertilizer use efficiency. The facts mentioned before necessitate researches in the field of both water and fertilizers use efficiency. Tollenaar and Lee [3] contended that yield improvement was generally accompanied with increase in both total water and fertilizer use efficiency. But when yield increase was greater than the increase in evapotranspiration, WUE improvement would be achieved. El-Gendy *et al*. [4] found that using slow release fertilizers in reclaimed sandy soil under modern irrigation methods increased water use efficiency via increasing crop yield/unit of applied water. El-Gendy and Abdel-Aziz [5] conducted a field experiment to study the effect of both irrigation methods and irrigation schedule on yield and water use efficiency of maize crop (single cross 10), they found that higher grain yields were obtained with drip irrigation than that with the sprinkler one and daily drip irrigation resulted in the highest water use efficiency.

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Zhang *et al.* [6] stated that for reducing water use it is necessary to examine the possibility of further reducing irrigation applied by optimizing the irrigation scheduling. According to Ashcroft *et al.* [7] good design and management (operation and maintenance) were crucial in achieving high water use efficiency, irrespective the delivery system used. They added that sometime, proper water management could be more appropriate than merely using a sophisticated irrigation method.

According to Fillery *et al.* [8] utilization of N from it's fertilizers ranges from 35 to 60%. The main reasons for low N consumption is mainly due to leaching and volatilization process. Smil [9, 10] found that only 30-50 and 45% of the applied N and P fertilizers are lost from agricultural fields, respectively. On the other hand, Waddel *et al.* [11] found that the total N uptake by potato plant was nearly 100% of that applied via sprinkler and drippers. Bar-Yousef *et al.* [12] indicated that sweet corn response to P applied via drip fertigation in calcareous soil was stronger than that to broadcasting P-fertilization. Singh and Sood [13] revealed that tuber yield of potatoes increased with increasing N-application rates under furrow, drip and sprinkler irrigation methods.

Increasing NUE is unlikely unless a systems approach is implemented that uses varieties with high harvest index, incorporated NH_4-N fertilizer, application of prescribed rates consistent with in-field variability using sensor-based systems within production fields, low N rates applied at flowering and forage production systems [14].

Mohammed *et al.* [15] demonstrated that N-application gave lower potato yield than the fertigated treatments. On the other side, Nimah *et al.* [16] found no significant difference in potato yield was obtained between the conventional and fertigation methods of fertilization. Generally, there are variety of practices and improvement which could contribute to increasing fertilizer use efficiency [4, 17].

Yakout [18] said that the use of fertigation technique significantly increased the water use efficiency compared to the banding one. Hassan Amal [19] mentioned that slow release fertilizers application through drip and sprinkler irrigation methods increased water use efficiency by potato plant.

The main objective of this paper is to study the effect of irrigation methods on the use efficiency of both water and soil applied fertilizers.

MATERIALS AND METHODS

Field experiments were carried out in two sites, Bahteem-Shoubra El-Khiema district and Shalaqan-Al-Kanater El-Khairea district, Qalubia Governorate. Some soil physical and chemical properties are shown in Table 1. Three crops were grown in both sites onion (*Allium cepa* L., Giza 20), potato (*Solanum tubersum*, Sponta holand) and peas (*Pisum sativum*, Master B-short). Different irrigation methods were used as follows: un-controlled surface, controlled surface drip and sub-surface drip, UCSI, CSI, SDI and SSDI, respectively. Used fertilizers were applied broadcasting besides plants. Tables 2 and 3 illustrates the irrigation method, cultivated crop and area of each, onion only was cultivated in both sites.

Onion was fertilized in the two sites as follows:

- 450 kg fed^{-1} superphosphate (15.5% P_2O_5) in two equal doses, the 1st was applied during soil preparation and the 2nd after 45 days from planting.
- 500 kg fed^{-1} ammonium sulphate (20.5%N) were applied to the soil in three equals doses 45, 75 and 105 days after planting.
- 150 kg fed^{-1} potassium sulphate (48% K_2O) were applied 105 days after planting.

Potato crop was fertilized using the recommended doses as follows:

- 400 kg fed^{-1} superphosphate (15.5% P_2O_5) were applied in two equal doses. The 1st was added during soil preparation while the 2nd 45 days after planting.
- 600 kg fed^{-1} ammonium sulphate (20.5% N) were applied to the soil in three equals doses during soil preparation and 40 and 61 days after planting.
- 150 kg fed^{-1} potassium sulphate (48% K_2O) were applied 105 days after planting.

Peas crop was fertilized using the following recommended doses:

- 400 kg fed^{-1} superphosphate (15.5% P_2O_5) in three doses, the 1st was 100 kg fed^{-1} was applied during soil preparation and 150 kg fed^{-1} were applied 45 and 90 days after planting.

- 400 kg fed^{-1} ammonium sulphate (20.5% N) were applied to the soil in three equals doses during soil preparation 45 and 90 days after planting.
- 150 kg fed^{-1} potassium sulphate (48% K_2O) were applied in two doses, the 1st dose during soil preparation and the 2nd one 45 days after planting.

Some soil characteristics were determined as follows: soil particle size distribution by pipette method after [20], soil organic matter was measured by Walkly-Black method [21], electrical conductivity in soil saturated extract by EC meter and pH (1:2.5 soil:water) Bower method [22]. Soil water content by weight at the field capacity and wilting point was measured after [23] on samples passing a 2 mm sieve, saturated for 24 h and then equilibrated for 24 h at 33 and 1500 kPa on a tension table and pressure-plate apparatus, respectively. Available Water (AW = FC-WP) was calculated. Available water % (w/w) [soil water content % (w/w) at field capacity-soil water content % (w/w) at wilting point] was calculated. Water crop requirements (m^3 fed^{-1}) was calculated using class A Pan evaporation method [24].

Water Use Efficiency (WUE) was calculated as follow:

- WUE = Yield (kg)/water consumptive used (m^3)
- Fertilizer use efficiency (WUE) was calculated as follow:
- FUE = Yield (kg)/fertilizer consumptive used (kg).

Data were subjected to analysis of variance, correlation and multiple regressions after Dospekhov [25].

RESULTS AND DISCUSSION

Table 1 illustrate some physical and chemical characteristics of the soils in both sites. It can be observed that the soil are clay loam in the 1st and two upper layers in Shalaqan and Bahteem sites, respectively, while texture was clay in the second two layer in Shalaqn site. Both experimental soils are moderately in pH, poor in OM % and have low amount of $CaCO_3$ %. Electrical conductivity values varied from 0.5 to 0.6 dS m^{-1}.

Table 2 shows WUE as affected by irrigation methods and crop. Data on hand reveal that WUE in kg_y m^{-3}varied from 6.45 (SDI) to 10.37 (CSI) and from 2.47 (SSDI) to 5.08 (CSI) for onion and peas crop, respectively at Bahteem site. At Shalaqan site, results of Table 3 indicates that irrigation method UCSI has the maximum value of WUE, while CSI has the lowest one (10.2 and 4.96 kg m^{-3} irrigation water, respectively for onion crop.

In the case of potato crop, the maximum and minimum values of WUE were 3.12 and 0.9 kg_y m^{-3} irrigation water under UCSI and SSDI, respectively. Also, data show that there were significant differences between irrigation methods used in Bahteem and Shalaqan sites except between UCSI (3.12) and SDI (2.04) in last one. It was noticed that, there were no significant differences between irrigation methods used from side and between the studied sites from the other one.

Table 2 illustrate the effects of irrigation methods, crop and experimental site on FUE. One can notice that FUE varies in the ranges: 111.30-171.17, 158.44-243.68, 163.56-251.54 kg yield kg^{-1} of fertilizers used, according to irrigation methods for N, P_2O_5 and K_2O fertilizers, respectively, in the case of onion crop at Bahteem site. But in case of peas crop, for the same site, the FUE values ranges were 50.44-90.34, 66.71-119.48 and 43.08-77.70 in the same sequence mentioned before. Regardless of the fertilizer, there were significant differences in FUE among irrigation methods used and they could be arranged in following descending order: CSI > UCSI > SDI > SSDI and CSI > SSDI > UCSI > SDI in the case of peas and onion, respectively. According to Tables 2 & 3, onion crop was more effective in FUE than peas and potato

Table 1: Some physical and chemical characteristics of the experimental sites

	Particle size distribution %					Θ % at					
Depth (cm)	Sand	Silt	Clay	Texture	BD g cm^{-3}	FC	WP	AW mm	pH	EC dS m^{-1}	OM %
Shalaqan site											
0-20	32.50	35.50	32.00	Clay loam	1.15	37.85	16.15	5.01	7.35	1.55	1.15
20-40	23.50	38.50	38.00	Clay	1.15	36.55	17.05	4.49	7.50	1.30	0.75
40-60	20.50	39.00	40.50	Clay	1.25	33.85	17.15	4.18	7.45	1.60	0.45
Bahteem site											
0-20	35.15	38.00	26.85	Clay loam	1.36	36.50	13.00	6.39	7.75	0.90	1.15
20-40	32.35	35.55	32.10	Clay loam	1.26	35.00	12.00	5.80	8.00	0.55	1.00
40-60	33.50	35.20	31.30	Clay loam	1.31	36.50	13.00	6.03	8.00	0.75	0.60

Θ: % moisture, FC: Field Capacity, WP: Wilting Point, AW: Available Water, OM: Organic Matter

Table 2: Fertilizer and water use efficiency as affected by irrigation methods, crop and fertilizers used at Bahteem site

Crop	Irrigation methods	Area m^2	WUE $kg_y\ m^{-3}$	Fertilizer use efficiency $kg_y\ kg^{-1}$ N	$kg_y\ kg^{-1}\ P_2O_5$	$kg_y\ kg^{-1}\ K_2O$
Onion	UCSI	500	6.63	114.05	162.36	167.60
	CSI	1000	10.37	171.17	243.68	251.54
	SDI	375	6.45	111.30	158.44	163.56
	SSDI	375	7.36	125.19	178.22	183.97
	Mean		7.70	130.43	185.68	191.67
Peas	UCSI	500	4.60	82.98	109.74	70.22
	CSI	1000	5.08	90.34	119.48	77.70
	SDI	375	2.63	52.80	69.84	45.10
	SSDI	375	2.47	50.44	66.71	43.08
	Mean		3.70	69.14	91.44	59.03
L.S.D. 5%	Irrigtion×crop		0.47	1.38	3.61	5.87
	Irrigation methods		-	4.70	3.82	6.20
	Crop		-	-	-	-

UCSI = Uncontrolled Surface Irrigation, CSI = Controlled Surface Irrigation, SDI = Surface Drip Irrigation, SSDI = Subsurface Drip Irrigation, WUE = Water Use Efficiency

Table 3: Fertilizer and water use efficiency as affected by irrigation methods, crop and fertilizer used at Shalaqan site

Crop	Irrigation methods	Area m^2	WUE $kg_y\ m^{-3}$	Fertilizer use efficiency $kg_y\ kg^{-1}$ N	$kg_y\ kg^{-1}\ P_2O_5$	$kg_y\ kg^{-1}\ K_2O$
Onion	UCSI	400	10.20	168.59	247.74	240.00
	CSI	336	4.96	88.49	130.04	125.97
	SDI	600	9.36	155.71	228.82	221.67
	SSDI	600	8.05	135.72	198.85	192.64
Mean			8.14	137.13	201.36	195.07
Potato	UCSI	400	3.12	60.33	119.68	77.23
	CSI	336	1.77	39.67	78.71	50.83
	SDI	600	2.04	43.82	86.94	56.15
	SSDI	600	0.90	26.34	52.26	33.75
Mean			1.96	42.54	48.40	54.49
L.S.D. 5%	Irrigtion×crop		0.34	4.85	14.32	3.08
	Irrigation methods			5.52	25.3	3.16
	Crop			17.9	17.89	22.40

UCSI = Uncontrolled Surface Irrigation, CSI = Controlled Surface Irrigation, SDI = Surface Drip Irrigation, SSDI = Subsurface Drip Irrigation, WUE = Water Use Efficiency

crops. FUE values of onion crop were about 1.88, 1.95 and 3.25; and 3.22, 4.16 and 3.58 times those of peas and potato crops, respectively for N, PO_5 and K_2O. These finding agreed with Chawla and Narda[27] who found that N fertilizer placement and timing and effective irrigation management are important considerations in promoting efficient N use that will also maintain groundwater quality. Also, increased irrigation water under UCSI and CSI methods help in solubility of added fertilizer and hence good uniformity for both water and fertilizer.

According to irrigation methods used, it was noticed that the FUE values varied from 88.49-168.59, 130.04-247.74 and 125.97-240.00 kg yield kg^{-1} of fertilizers used in the case of N, PO_5 and K_2O fertilizers used, respectively, for onion crop at Shalaqan site. Concerning potato crop, FUE values varied from 26.34-60.33, 52.26-119.68 and 33.75-77.23 kg yield kg^{-1} of fertilizers used under SSDI

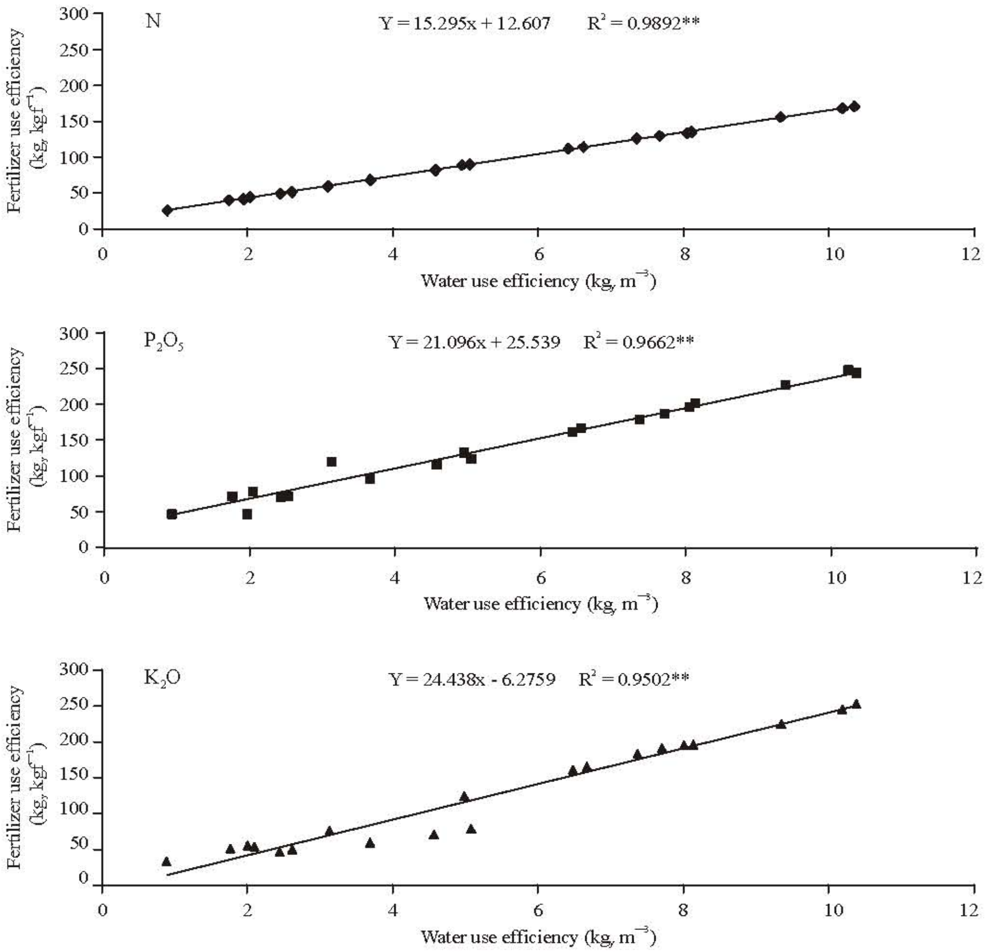

Fig. 1: The relationship between water and fertilizer use efficiency

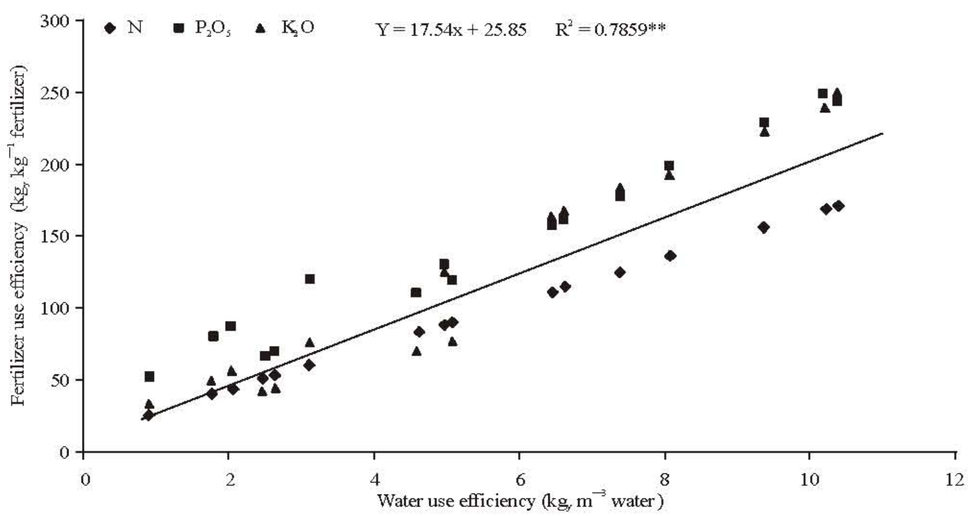

Fig. 2: Fertilizer use efficiency as affected by irrigation use efficiency

Table 4: Fertilizer use efficiency of onion crop as affected by irrigation methods, site and fertilizer used

Experimental site	Irrigation methods	WUE $kg_y\ m^{-3}$	Fertilizer use efficiency $kg_y\ kg^{-1}$ N	$kg_y\ kg^{-1}\ P_2O_5$	$kg_y\ kg^{-1}\ K_2O$
Bahteem	UCSI	6.63	114.05	162.36	167.60
	CSI	10.37	171.17	243.68	251.54
	SDI	6.45	111.30	158.44	163.56
	SSDI	7.36	125.19	178.22	183.97
	Mean	7.70	130.43	185.68	191.67
Shalaqan	UCSI	10.20	168.59	247.74	240.00
	CSI	4.96	88.49	130.04	125.97
	SDI	9.36	155.71	228.82	221.67
	SSDI	8.05	135.72	198.85	192.64
	Mean	8.14	137.13	201.36	195.07
L.S.D. 5%	Irrigtion×site		2.05	2.74	3.26
	Irrigation methods		2.69	3.23	4.28
	Site		1.89	2.28	3.03

Table 5: Simple correlation coefficient between the studied parameters

	WUE	FUE-N	FUE-P_2O_5	FUE-K_2O
WUE	-			
FUE-N	0.9998**	-		
FUE-P_2O_5	0.9830**	0.9860**	-	
FUE-K_2O	0.9758**	0.9748**	0.9797**	-

and UCSI irrigation methods in the case of N, PO_5 and K_2O fertilizers, respectively. These agree with Berle and Keeny [26] who indicated that potato growth was better in the trickle fertigated crop than in furrow irrigated one. These results could be attributed to demand of the used fertilizers to excessive water to increase its availability for plant uptake [27].

Regardless of the cultivated crop, there were significant differences among irrigation methods. Accordingly the irrigation methods could be arranged in this descending order: UCSI > SDI > SSDI > CSI. Regardless of the experiment site, it was noticed that, there were significant differences ($p = 0.05$) in FUE values between irrigation methods except between CSI and SSDI (Table 4). Shalaqan site has a more pronounced effect on FUE than Bahteem one under different fertilizers used in case of onion crop. It is worthy to mention that the FUE of the fertilizers under study by onion crop at Bahteem site exceeded that at Shalaqan one. These result agreed with Thompson *et al.* [28] who stated that subsurface drip irrigation offers potential for increased water and fertilizer use efficiency.

Simple correlation coefficients were calculated between WUE and FUE of N, P_2O_5 and K_2O used (Fig. 1). Data on hand, indicate highly positive significant correlations at 1% between the studied variables. The results reveal the importance of increasing WUE to get more benefit from the applied fertilizers.

In addition, simple regression analysis between WUE and FUE was carried out regardless of crop and site (Fig. 2). Simple regression equation highly significant at 1% level was found between WUE and FUE which could be written as follows:

$$FUE = 17.54\ WUE + 0.78\ R^2\ 0.9981^{***}$$

It could be concluded that there was close linear relationship between WUE from side and FUE from other one. This means any increase in WUE is followed by significant increase in FUE. So, any saving in irrigation water increases WUE, FUE and farmer profit. On the other hand it decreases fertilizers consumption and pollution of both soil and water.

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