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Potato Productivity in Response to Furrow Irrigation Practices, Rabbit Manure Rates, and Potassium Fertilizer Levels

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A field experiment was carried out during the winter seasons of 2018/19 and 2019/20 at Agricultural Experimental Farm, Faculty of Agricultural, Al-Azhar University, Assiut, Egypt. To assess the effect of two furrow irrigation practices (conventional; CFI, and alternate; AFI), three rabbit manure application rates (R_0, R_1 and R_2) and three potassium sulfate levels (KS_0, KS_1, and KS_2) on potato yield and its macronutrient contents and on some water relations. Also to develop local potato crop coefficient (Kc). The experiment was laid out in split-split plots design with three replicates. The obtained results indicated that, the CFI practice with $R0KS_0$ realized the highest amount of both WCU and IWA through both seasons, it was 5399.7 and 7523.4 m^3 ha^{-1}, respectively. While the lowest amount of WCU and IWA were obtained by AFI practices with R2KS2 through both seasons it was 4063.7 and 5455.8 m^3 ha^{-1}, respectively. The highest values of both irrigation and crop water productivity were attained by AFI with R_2KS_2 through both seasons it was 9.42 and 7.02 kg m^{-3}, respectively. While the lowest values were obtained by CFI with R_0KS_0 through both seasons for the corresponding parameters it was 4.42 and 3.16 kg m^{-3}, respectively. Kc value started to increase at the beginning to reach its maximum value (Kc mid) at the time of near mature plant, it varied from: 0.63, 0.70, 1.03 and 0.98 for initial, development, mid and end season stages, respectively. The highest amount of saved water (28.23%) was attained by AFI practices with R_2KS_2 through both seasons compared to CFI with R_0KS_0. Generally, the potato tuber yields and N, P, K content were significantly influenced by furrow irrigation practices, as well as by adding rabbit manure and potassium sulfate, the highest yields were 37.87 and 38.35 ton ha-1 for first and second seasons, respectively under AFI.

Keywords: Furrow irrigation, Rabbit manure, Potassium sulfate, Water consumptive use, Crop coefficient, Water productivity, Potato yield.

Introduction

Drought is a severe environmental stress limiting agricultural production in many countries. However, in Egypt water availability for agriculture production is being reduced as a consequence of global climate change, and growing demand for other uses. Therefore, great emphasis is placed on water management for dry conditions based on plant physiology, with the aim of increasing water use efficiency. In recent years, however, growing competition for scarce water resources has led to applying modified techniques for maximizing water use efficiency and improving crop yields and quality, particularly in arid and semi-arid regions as like Egypt (Abdelraouf, 2016). Water conservation or partially root-zone irrigation is defined as the use of alternate furrow irrigation with reduced applied water to increase water production. Water infiltration into soil surface occurs in both directions horizontal and vertical (2-dimensional) and the fronts of infiltrate water from two adjacent furrows were overlap in the horizontal direction (Sepaskhah and Hosseini, 2008). Tafteh and Sepaskhah (2012) found that the cumulative deep percolation is lower at alternative furrow irrigation and fixed alternative furrow irrigation compared to continuous furrow irrigation. The partially root-zone irrigation strategy is an improvement over the deficit irrigation strategy in which irrigation is alternated spatially and

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temporally to produce wet–dry cycles in many parts of the root zone (Morison et al., 2008 and Zin El-Abedin et al., 2019). Sarker et al. (2019) discovered that potato tuber yield, tuber quality, and potato water productivity were positively affected by alternative furrow irrigation in a raised bed system while potato yield slightly varied between alternative furrow irrigation and conventional furrow irrigation. Also, alternative furrow irrigation practice saved 35% of irrigation water and significantly improved irrigation water productivity by 50% compared to conventional furrow irrigation one. Abdel-Aziz et al 2017, studied the effect of applied irrigation water regimes on marketable yield, plant quality parameters, water use efficacy (WUE), irrigation water use efficiency (IWUE) and yield response factor (Ky) of potato (Solanum Tuberosum L.) crop. The values of potato Ya under IR=100% treatment increased significantly by about 34 % compared to those under control treatment. Moreover, the maximum values of WUE and IWUE for potato tubers were 11.28 and 5.89 kg m-3, respectively, under IR=80% and SSDI treatment. The water productivity of conventional furrow irrigation could significantly be improved and substantial amount of water saved without significant yield reduction by renovating to alternative furrow irrigation technique (Du et al., 2010). Under semi-arid region, Kadam et al. (2021) revealed that potato Kc values during the vegetative, tuber development, and maturity stages were 0.55, 1.11, and 1.01, respectively. Under full irrigation and PRD for tomato crop, the highest tomato yields were obtained with the FULL (100% ETo) irrigation and high K application. Also, the proline concentration increased with increasing water stress. For PRD treatments, proline concentrations in the wet were less than dry side. The abscisic acid (ABA) concentration increased by many folds with PRD and DI techniques as compared to FULL irrigation. On the other hand, WUE increased with increasing K level and/or decreasing the amount water consumed by plants. The highest average WUE values were obtained with PRD and DI (Abdelhalem, 2007). Organic matter can improve soil structure and aeration, reduce soil bulk density, enhance water infiltration and retention, and increase microbial populations (Agbede et al., 2013). Sakara 2020 revealed that application of 75% N from recommended dose had maximum significant effect on vegetative growth and substantially improved the quantitative and qualitative traits of tuber yield. Also, with foliar application of Fe-EDTA results increase in vegetative growth parameters. Organic fertilizers are frequently or partially used instead of mineral fertilizers to achieve sustainability of agricultural ecosystems without compromising productivity or quality (Hernández et al., 2016 and Abuarab et al., 2019). On the other hand, El-Dissoky 2019 reported that the form of nitrogen fertilizer is one of the important limitation factors for potato yield and quality, which depends primarily on the availability and cost of fertilizers. Bera et al. (2019) observed that applying different doses of potassium fertilizer significantly affected plant growth and potato yield. Elkhatib et al. (2019) reported that the potato growth parameters were increased as a result of adding 64 and 96 Kg K2O/ fadden in combination with bio fertilizer. Abou zeid and El-Latif, 2017, showed that yield and quality of tuber increased with increasing potassium rates up to 120 kg K2O/fed. In both seasons, the highest tuber yield was 14.85 ton/fed with potassium sulphate at 120 kg K2O/fed. Also, Abd-Elrahman et al 2018, Potassium (K) is an essential element for plant growth that maintains water balance within its cells. The 50% irrigation level of irrigation requirements (IR) combined with K-humate as ground application increased water soluble and exchangeable K in the studied soil. Regarding the studied vegetative growth and yield parameters of the growing.

The study aims to evaluate the influence of different furrow irrigation practices, rabbit manure application rates and potassium sulfate levels on some water relations, potato yield and its NPK contents, and to develop a local potato crop coefficient (Kc).

2-Materials and Methods

A field experimental was conducted during the winter seasons of 2018/19 and 2019/20 at The Agricultural Experimental Farm, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt (27o 12- 16.67= N latitude and 31o 09- 36.86= E longitude). The present research was conducted to study the effect of furrow irrigation practices, rabbit manure application rates and potassium sulfate levels on potato-water relations, potato yield and its NPK contents, and to develop local crop coefficient (Kc). The experiment was laid out in split split plots design with three replicates and consisted of 18 treatments. The main plots were allocated to two furrow irrigation practices (conventional furrow irrigation; CFI, and alternate furrow irrigation; AFI) that were bounded with buffer zone of 2 m width to avoid the horizontal seepage. The split units were assigned for rabbit manure application rates (Ro: 0; R1: 6; and R2: 12 ton ha-1). The split-split units were devoted to potassium sulfate levels (KS0: control, KS1: 85 kg K2O ha-1, and KS2: recommended dose; 170 kg K2O ha-1). The experimental plot has an area of 16 m2 (4 m width × 4m length). The potato (Cara. cv.) was planted on the 10th of October in both growing seasons. Potato plants were harvested 120 days after planting. Potato fertilization was preformed according to the recommended doses by Ministry of Agriculture (285 kg N ha-1and 180 kg P2O5 ha-1).

At the experimental site, disturbed and undisturbed soil samples from the surface (0 – 30 cm) and (30 – 60 cm) layers were collected for physical and chemical analysis. The researche area's important physical and chemical parameters were determined according to Page (1982) and Klute (1986) and the obtained values are shown in Table 1.

TABLE 1. Some soil chemical and physical properties of the experimental site

A- Chemical properties:

Soil depth (cm)	**OM (g/kg)**	**$CaCO_3$ (%)**	**pH**	**SP**	**ECe (dS/m)**	**SAR**	**Available nutrients (ppm)**		
							N	**P**	**K**
0-30	17.12	3.50	7.94	76	1.21	3.75	68.35	10.10	130
30-60	14.25	3.34	7.98	75	1.14	3.64	66.00	9.65	125

OM = organic matter, pH= soil reaction, SP = saturation percent, ECe = salinity in soil past extract, SAR= sodium adsorption ratio.

B- Physical properties

Depth (cm)	Particle size analysis (%)			Texture class	Moisture content θ v%		AW (%)	B_d (g/cm^3)	Inf. rate (cm/h)	HC (m/day)
	Sand	Silt	Clay		FC	WP				
0-30	24.00	40.00	36.00	Clay Loam	38	19.0	19	1.38	0.21	0.08
30-60	25.50	39.50	37.00	Clay Loam	37	18.0	19	1.42		

FC = field capacity, WP = wilting point, AW = available water, B_d= bulk density, Inf. Rate = infiltration rate, HC= hydraulic conductivity.

Applied irrigation water (AIW):

You have to present how you calculated the applied water (it is presented in Table 5)

You have to present how the applied water to the plot was measured.

Actual consumptive water use (CU or ETa):

The depth of water consumed (cm) from the root zone between two successive irrigations, was calculated from the following equation according to Israelsen and Hansen (1962).

CU=((D*Bd*(∅2-∅1))/100

Where:
CU = Actual consumptive water use cm).
D = the irrigation soil depth (cm).
Bd = bulk density of soil (g/cm3).
∅2 = the percentage of soil moisture at field capacity.
∅1 = the percentage of soil moisture before irrigation.

The soil moisture was measured gravimetrically on a dry basis just before and 24 hours after irrigation to obtain the actual water consumptive use.

Reference crop evapotranspiration (ETo)

The climatic parameters at the studied area during the two successive growing seasons are presented in Table 2.

TABLE 2. Average monthly meteorological data at Assiut agro-meteorol0gical station during the two seasons

Year	Month	T max (°C)	T min (°C)	RH (%)	WS (km/h)	Sunshine (hours)	ETo (mm/day)
2018	**October**	32.6	18.9	46.5	18.1	10.0	7.58
	November	26.5	13.1	53.8	14.7	9.4	4.93
	December	20.8	8	62.8	16.3	9.0	3.62
2019	**January**	19.3	5.8	52.8	13.9	8.9	3.70
	October	33.6	19.3	47.6	16.9	10.0	7.52
	November	28.6	13.7	52	14	9.4	5.27
	December	21.5	8.1	57.7	15.4	9.0	3.86
2020	**January**	20.4	6.2	53.3	16.2	8.9	3.77

T max = maximum air temperature, T min = minimum air temperature, RH = Relative humidity,
WS = wind speed, ET_o = reference crop evapotranspiration.

Reference crop evapotranspiration (ET_o) is estimated by the FAO Penman-Monteith method using the CROPWAT 8.0 model, which was reported in FAO Irrigation and Drainage Paper 56. (FAO 1998).

The FAO CROPWAT program (FAO, 2009) includes procedures for calculating reference crop evapotranspiration and crop water requirements, as well as crop water consumption simulations under a variety of climate, crop, and soil circumstances.

Potato crop coefficient (Kc)

The crop Kc is calculated as the ratio of crop ET_a and the reference crop evapotranspiration (ET_o)

$$Kc = \frac{ETa}{ETo}$$

Where:

ET_a = actual evapotranspiration measured for the grown potato crop (mm/day).

ET_o = reference crop evapotranspiration (mm/day).

Potato-water productivities

The irrigation water productivity of the marketable potato yield (kg tuber/m^3 of water). The potato-water productivity values were calculated according to Bos (1985) as follows:

- Crop Water Productivity (kg m^{-3}):

$$CWP = \frac{Tuber\ Yield\ (\frac{kg}{ha})}{Consumed\ Water\ (\frac{m^3}{ha})}$$

- *Irrigation Water Productivity (kg m^{-3}):*

$$IWP = \frac{Tuber\ Yield\ (\frac{kg}{ha})}{Applied\ Water\ (\frac{m^3}{ha})}$$

- Water saving m^3 ha^{-1}):

$$WS = \frac{Applied\ water\ with\ (CFI)}{Applied\ Water\ with\ (AFI)}$$

Potato Yield and NPK contents

At harvest time, 2 m^2 (1m x 2m) from each center area of plot were used to estimate potato yield then converted to yield/ha. The following parameters were determined:

1- Potato tubers yield (ton ha^{-1}).
2- Nitrogen content (g kg^{-1})
3- Phosphorus content (g kg^{-1}).
4- Potassium content (g kg^{-1}) .

Statistical Analysis

One-way analysis of variance (ANOVA) and Duncan's multiple range test was used to determine the statistical significance of the differences between the treatment's effects on potato water relationships and yield. The analysis used SPSS software, and $p < 0.05$ was considered statistically significant.

3-Results and Discussion

1- Actual and reference crop evapotranspiration during different growth stages of potato plant:

Actual evapotranspiration (ETa) values as affected by different furrow irrigation practices, rabbit manure rates and potassium sulfate application levels during the potato growth stages in winter seasons of 2018/19 and 2019/20 are presented in Table 3. Results indicated that, the furrow irrigation treatments affected the ETa in both seasons. The ETa values were higher under conventional furrows than those of alternative ones.

TABLE 3. Actual and reference crop evapotranspiration (mm) as affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato growth stages during winter seasons of 2018/19 and 2019/20

Treatments		Growth stage				
Irrigation patterns	rabbit manure and K_2SO_4	Initial (25 day)	Development (40 day)	Mid-season (30 day)	Late-season (25 day)	Gross season (120 day)
			2018/2019			
CFI	R_0+KS_0	132.1 a	168.64 a	131.22 a	106.2 a	538.16 a
	R_0+KS_1	131.35 a	168.25 a	130.75 a	105.95 a	536.3 a
	R_0+KS_2	130.75 a	167.85 a	130.12 a	104.76 a	533.48 b
	Average R_0	131.4	168.2	130.7	105.6	536
	R_1+KS_0	128.45 b	161.67 b	122.35 b	100.85 b	513.32 c
	R_1+KS_1	126.55 c	160.45 b	121.75 b	98.35 c	507.1 d
	R_1+KS_2	125.85 c	157.95 c	120.35 c	97.55 d	501.7 e
	Average R_1	127	160	121.5	98.9	507.4
	R_2+KS_0	120.45 d	152.82 d	118.65 d	95.75 e	487.67 f
	R_2+KS_1	119.65 de	151.65 de	117.45 de	93.75 f	482.5 g
	R_2+KS_2	117.52 e	150.65 e	115.85 e	91.82 g	475.84 h
	Average R_2	119.2	151.7	117.3	93.8	482
AFI	R_0+KS_1	114.27 f	145.37 f	113.25 f	91.11 h	464 i
	R_0+KS_2	113.52 f	144.95 f	112.2 f	89.35 h	460.02 j
	Average R_0	113.9	145.2	112.7	90.2	462
	R_1+KS_0	111.15 g	140.29 g	106.12 g	86.59 i	444.15 k
	R_1+KS_1	109.85 h	138.15 gh	104.22 gh	84.11 j	436.33 l
	R_1+KS_2	108.48 h	137.42 h	103.04 h	83.18 j	432.12 m
	Average R_1	109.8	138.6	104.5	84.6	437.5
	R_2+KS_0	104.15 i	132.34 i	102.87 hi	81.53 k	420.89 n
	R_2+KS_1	103.25 i j	130.93 j	101.81 i	79.25 l	415.24 o
	R_2+KS_2	100.24 k	128.85 k	99.12 j	77.45 m	405.66 p
		102.5	130.7	101.3	79.4	413.9
			2019/2020			
CFI	R_0+KS_0	133.13 a	169.79 a	132.98 a	105.87 a	541.77 a
	R_0+KS_1	132.85 a	169.25 a	132.75 a	105.55 a	540.4 a
	R_0+KS_2	131.95 a	168.85 a	131.62 a	103.79 a	536.21 b
	Average R_0	132.6	169.3	132.5	105.1	539.5
	R_1+KS_0	129.75 b	162.86 b	123.75 b	99.89 b	516.25 c
	R_1+KS_1	127.59 c	162.25 b	122.55 bc	97.75 c	510.14 d
	R_1+KS_2	126.65 c	159.55 c	121.65 c	96.65 c	504.5 e
	Average R_1	128	161.6	122.7	98.1	510.3
	R_2+KS_0	121.87 d	154.35 d	119.87 d	94.78 d	490.87 f
	R_2+KS_1	120.98 d	152.95 e	118.65 de	92.97 e	485.55 g
	R_2+KS_2	118.65 e	151.85 e	117.45 e	91.25 f	479.2 h
	Average R_2	120.5	153.1	118.7	93	485.2
AFI	R_0+KS_1	115.17 f	146.31 f	114.21 f	89 g	464.69 I
	R_0+KS_2	114.35 f	145.76 f	113.15 g	88.13 g	461.39 j
	Average R_0	114.8	146	113.7	88.6	463
	R_1+KS_0	112.11 g	141.19 g	107.09 h	85.29 h	445.68 k
	R_1+KS_1	110.65 h	139.07 h	105.22 i	83.03 i	437.97 l
	R_1+KS_2	109.41 h	138.27 h	104 i	82.11 j	433.79 m
	Average R_1	110.7	139.5	105.4	83.5	110.7
	R_2+KS_0	105.18 i	133.24 i	103.64 j	80.35 k	422.41 n
	R_2+KS_1	104.22 i	131.68 i	102.63 jk	78.14 l	416.67 o
	R_2+KS_2	101.12 j	129.55 j	100.12 k	76.29 m	407.08 p
	Average R_2	109.41	138.27	104	82.11	109.41
ETo 2018/19		189.5	207.9	108.8	92.5	598.7
ETo 2019/20		188	218.7	115.5	94.3	616.4

(CFI = conventional furrow irrigation - AFI alternate furrow irrigation) - (R_o= 0, R_1= 6 and R_2= 12 ton ha^{-1} Rabbit Manure) - (KS_0= 0, KS_1= 85 and KS_2= 170 kg K_2O ha^{-1})

Also, it was noticed that the ET_a values at the different potato growth stages were slightly higher in2019/20 season than those of 2018/19 season. This may be due to the variation in the weather conditions, especially temperature (Table 2). The higher temperature would automatically result in higher water consumptive use. This pattern is consistent with that observed by Attia et al. (2015), Yang et al. (2015), Abdel-Aziz et al. 2017 and EL-Sayed, et al. (2020). Also, the results in Table 3 demonstrated that the rabbit manure and potassium sulfate affected ET_a values since they decreased as rabbit manure and potassium sulfate applications increased compared to control treatment (zero addition). The addition of organic amendments with Mycorrhiza improved porosity, hydraulic conductivity and soil structure and contract decreased (Celik et al., 2004). Also, a factor in managing cropresidue and erosion control as indicated by increased aggregate stability in soil (McVay et al., 2006).

The reference crop evapotranspiration (ET_o) in Table 2 values which they estimated by the empirical equation of FAO Penman-Monteith in both seasons revealed that the ET_o values started high according to the high temperature in the early stage (Table 2). The results indicated that ET_o at the different stages slightly increased in winter season of 2019/20 compared to that of 2018/19. This may be due to the variation in the weather conditions, especially temperature. The higher temperature would automatically result in higher reference evapotranspiration.

2- Crop coefficient (Kc)

The crop coefficient reflects all the crop characteristics (sowing date, rate of crop development and length of growing season) under certain climatic conditions. Due to the variations in the crop characteristics throughout its growing season, Kc values for a given crop changes from sowing till harvest. For potato crop the values of Kc were small under all treatments shortly after planting. The Kc values started to increase from the initial Kc value at the beginning and reached a maximum value (Kc mid) at the time of maximum or near maximum plant end. This tendency was obtained in both growing seasons (Table 4). In general, the calculated Kc values at different potato growth stages were not always identical in both seasons. They were less in the second season than those in the first one. The average Kc values varied from: 0.63, 0.70, 1.03, 0.98 and 0.93 for initial, development, mid and end season stages, respectively. The Kc values were under CFI were higher than under AFI treatments in two seasons. It was 0.67, 0.78, 0.1.14 and 1.09 for CFI and 0.59, 0.68, 1.0 and 0.94 for AFI for initial, development, mid and end season respectively in the first season. But in the second one it was 0.67, 0.73, 0.1.07 and 1.04 for CFI and 0.58, 0.63, 0.92 and 0.88 for AFI for initial, development, mid and end season respectively in the first season. These results agree with those obtained by Alatway et al. (2019) and Kadam et al. (2021).

3- Potato crop water relations:

The highest value of water consumption use (WCU) and irrigation water applied (IWA) were realized under CFI with R_0 + KS_0 treatment and they were 5417.7 and 7587.65 m^3 ha^{-1}, respectively in the 2nd season (Table 5). The lowest values of WCU and IWA were attained under AFI with R_2+KS_2 treatment and they were 4056.60 and 5465.64 m^3ha^{-1}, respectively in the 1st season. These findings are in agreement with those obtained by Gebremariam et al. (2018) and Sarker et al. (2019).

Crop water productivity (CWP) and irrigation water productivity (IWP) as affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato plants in winter season of 2018/19 and 2019/20 is presented in Table (5). The furrow irrigation treatments affected CWP and IWP through both seasons since they were increased under AFI practice but they decreased under CFI through both seasons. The highest values of CWP (9.49 kg m^{-3}) and IWP (7.10 kg m^{-3}) were recorded under AFI with R $_2$+KS_2 in the 2nd season. The lowest values of CWP (4.38 kg m^{-3}) and IWP (3.16 kg m^{-3}) were recorded under CFI with R_0+KS_0 in the 1st season. It could be concluded that conventional furrow irrigation (CFI) practiced by many farmers causes an increase in the irrigation water applied which negatively affects soil properties, fertilizers and ground water over the long term. So the alternate furrow irrigation (AFI) is suitable to achieve high potato production with minimum water applied. These results are consistent with those obtained by Gebremariam et al. (2018), Sarker et al. (2019) and Elglaly et al. (2021). Also, the rabbit manure and potassium sulfate applications realized positive significant effects on CWP and IWP. Results indicated that, CWP values increased with increasing rabbit manure and potassium sulfate applications compared to zero addition (control treatment), while the IWA values decreased with increasing the rates of manure and potassium levels. The obtained results are due to improving soil water holding capacity with increasing the application rates of manure and the role of potassium in enhancing crop ability to water stress.

TABLE 4. Crop coefficient Kc (mm) as affected by furrow irrigation, rabbit manure and potassium sulfate applications for Potato crop through growth stages during winter season of 2018/19 and 2019/20

Treatments		Growth stage				Average
Irrigation patterns	rabbit manure and k_2SO_4	Initial (25 day)	Development (40 day)	Mid (30 day)	End (25 day)	
2018/2019						
CFI	R_0 +KS_0	0.7 a	0.81 a	1.21 a	1.15 a	0.9
	R_0 +KS_1	0.69 a	0.81 a	1.2 a	1.15 a	0.96
	R_0 +KS_2	0.69 a	0.81 a	1.2 a	1.13 a	0.96
	R_1+KS_0	0.68 a	0.78 ab	1.12 b	1.09 b	0.92
	R_1+KS_1	0.67 a	0.77 ab	1.12 b	1.06 c	0.91
	R_1+KS_2	0.66 a	0.76 b	1.11 b	1.05 c	0.9
	R_2+KS_0	0.64 ab	0.74 b	1.09 b	1.04 c	0.87
	R_2+KS_1	0.63 ab	0.73 b	1.08 bc	1.01 d	0.86
	R_2+KS_2	0.62 b	0.72 b	1.06 c	0.99 d	0.85
AFI	R_0 +KS_1	0.6 b	0.7 c	1.04 c	0.98 d	0.83
	R_0 +KS_2	0.6 b	0.7 c	1.03 c	0.97 d	0.82
	R_1+KS_0	0.59 b	0.67 c	0.98 d	0.94 e	0.79
	R_1+KS_1	0.58 b	0.66 c	0.96 d	0.91 e	0.78
	R_1+KS_2	0.57 bc	0.66 c	0.95 d	0.9 e	0.77
	R_2+KS_0	0.55 c	0.64 d	0.95 d	0.88 f	0.75
	R_2+KS_1	0.54c	0.63 d	0.94 d	0.86 f	0.74
	R_2+KS_2	0.53 c	0.62 d	0.91 e	0.84 fg	0.72
2019/2020						
CFI	R_0 +KS_0	0.71 a	0.78 a	1.15 a	1.12 a	0.88
	R_0 +KS_1	0.71 a	0.77 a	1.15 a	1.12 a	0.94
	R_0 +KS_2	0.7 a	0.77 a	1.14 a	1.1 a	0.93
	R_1+KS_0	0.69 a	0.74 b	1.07 b	1.06 b	0.89
	R_1+KS_1	0.68 a	0.74 b	1.06 b	1.04 b	0.88
	R_1+KS_2	0.67 a	0.73 b	1.05 b	1.03 b	0.87
	R_2+KS_0	0.65 b	0.71 c	1.04 c	1.01 bc	0.85
	R_2+KS_1	0.64 b	0.7 c	1.03 c	0.99 c	0.84
	R_2+KS_2	0.63 b	0.69 c	1.02 c	0.97 c	0.83
AFI	R_0 +KS_1	0.61 bc	0.67 cd	0.99 d	0.94 cd	0.8
	R_0 +KS_2	0.61 bc	0.67 cd	0.98 d	0.94 cd	0.8
	R_1+KS_0	0.6 c	0.65 d	0.93 e	0.9 d	0.77
	R_1+KS_1	0.59 c	0.64 d	0.91 e	0.88 d	0.75
	R_1+KS_2	0.58 c	0.63 d	0.9 e	0.87 d	0.75
	R_2+KS_0	0.56 cd	0.61 de	0.9 e	0.85 e	0.73
	R_2+KS_1	0.55 cd	0.6 de	0.89 e	0.83 e	0.72
	R_2+KS_2	0.54 d	0.59 e	0.87 ef	0.81 e	0.7

CFI = conventional furrow irrigation - AFI alternate furrow irrigation) - (R_o= 0, R_1= 6 and R_2= 12 ton ha^{-1} Rabbit Manure) - (KS_0= 0, KS_1= 85 and KS_2= 170 kg K_2O ha^{-1})

TABLE 5. Water consumptive use, irrigation water applied, crop water productivity and irrigation water productivity that affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato crop during winter season of 2018/19 and 2019/20

Treatments		Tubers Yield (Mg ha^{-1})	Water consumptive use (m^3 ha^{-1})	Irrigation water applied (m^3 ha^{-1})	Crop water productivity (Kg m^{-3})	Irrigation water productivity (k g m^{-3})
Irrigation systems	Rabbit manure and k_2 SO_4					
2018/2019						
CFI	R_0 +KS_0	23.56 o	5381.6 a	7459.96 a	4.38 j	3.16 j
	R_0 +KS_1	26.65 n	5363 b	7448.61 b	4.97 i	3.58 i
	R_0 +KS_2	28.45 l	5334.8 c	7307.95 c	5.33 h	3.89 h
	R_1+KS_0	28.50 l	5133.2 d	7080.28 d	5.55 h	4.03 h
	R_1+KS_1	30.75 i	5071 e	6913.43 e	6.06 g	4.45 g
	R_1+KS_2	32.65 g	5017 f	6802.71 f	6.51 f	4.80 f
	R_2+KS_0	32.45 g	4876.7 g	6642.2 g	6.65 f	4.89 f
	R_2+KS_1	33.56 f	4825 h	6537.94 h	6.96 e	5.13 e
	R_2+KS_2	35.35 c	4758.4 i	6434.62 i	7.43 de	5.49 de
AFI	R_0 +KS_1	26.97 m	4640 j	6312.93 j	5.81 g	4.27 gh
	R_0 +KS_2	28.64 k	4600.2 k	6254.52 k	6.23 fg	4.58 g
	R_1+KS_0	29.11 j	4441.5 l	6030.55 l	6.55 f	4.83 f
	R_1+KS_1	31.35 h	4363.3 m	5921.96 m	7.18 e	5.29 e
	R_1+KS_2	33.95 f	4321.17 n	5839.41 n	7.86 d	5.81 d
	R_2+KS_0	34.75 d	4208.87 o	5691.51 o	8.26 c	6.11 c
	R_2+KS_1	36.82 b	4152.4 p	5603.78 p	8.87 b	6.57 b
	R_2+KS_2	37.87 a	4056.6 q	5465.64 q	9.34 a	6.93 a
2019/2020						
CFI	R_0 +KS_0	24.15 l	5417.7 a	7587.65 a	4.46 j	3.18 j
	R_0 +KS_1	27.25 k	5404 b	7542.22 b	5.04 i	3.61 i
	R_0 +KS_2	28.76 j	5362.1 c	7447.36 c	5.36 h	3.86 h
	R_1+KS_0	28.98 i	5162.5 d	7084.53 d	5.61 gh	4.09 h
	R_1+KS_1	31.45 g	5101.4 e	6988.22 e	6.16 g	4.50 g
	R_1+KS_2	33.18 e	5045 f	6887.37 f	6.58 f	4.82 f
	R_2+KS_0	32.87 f	4908.7 g	6696.73 g	6.70 f	4.91 f
	R_2+KS_1	34.51 d	4855.5 h	6592.67 h	7.11 fe	5.23 e
	R_2+KS_2	35.88 c	4792 i	6475.68 i	7.49 de	5.54 de
AFI	R_0 +KS_1	27.35 k	4646.9 j	6318.01 j	5.89 g	4.33 g
	R_0 +KS_2	29.15 i	4613.9 k	5974.33 k	6.32 f	4.88 f
	R_1+KS_0	29.76 h	4456.8 l	6034.94 l	6.68 f	4.93 f
	R_1+KS_1	31.65 g	4379.7 m	5918.51 m	7.23 e	5.35 e
	R_1+KS_2	34.22 d	4337.9 n	5852.54 n	7.89 d	5.85 d
	R_2+KS_0	35.45 c	4224.1 o	5708.24 o	8.39 c	6.21c
	R_2+KS_1	37.23 b	4166.7 p	5604.17 p	8.94 b	6.64 b
	R_2+KS_2	38.65 a	4070.8 q	5445.89 q	9.49 a	7.10 a

CFI = conventional furrow irrigation - AFI alternate furrow irrigation) - (R_o= 0, R_1= 6 and R_2= 12 ton ha^{-1} Rabbit Manure) - (KS_0= 0, KS_1= 85 and KS_2= 170 kg K_2O ha^{-1})

4- The saved water:

The results in Fig (1 & 2) show that the highest amount of saved water (2141.76m^{3} ha^{-1}) was recorded under alternative furrow irrigation (AFI) with R_2+KS_2 treatment in the 2[nd] season compared to conventional furrow irrigation (CFI) with R_0+KS_0 treatment. The saved water was about 28.23% under AFI with R_{12}+$KS_{100\%}$ treatment compared to that of CFI with R_0+KS_0. In general, it could be concluded that the best method to irrigation potato should give the maximum crop yield and minimum amount of irrigation water. Therefore, estimating irrigation water economic becomes very important for planning irrigation management since over irrigation causes nutrients leaching and water losses resulting in low irrigation efficiency. The saved water under AFI with rabbit manure and potassium sulfate applications might be due to the lowest area of spreading irrigation water along the alternative furrows. The obtained results are compatible with those obtained by Ahmad et al., 2009; Ahamd et al., 2011; FAO, 2016; Sarker et al., 2016; EL-Sayed, et al. 2020 and Elglaly et al. 2021.

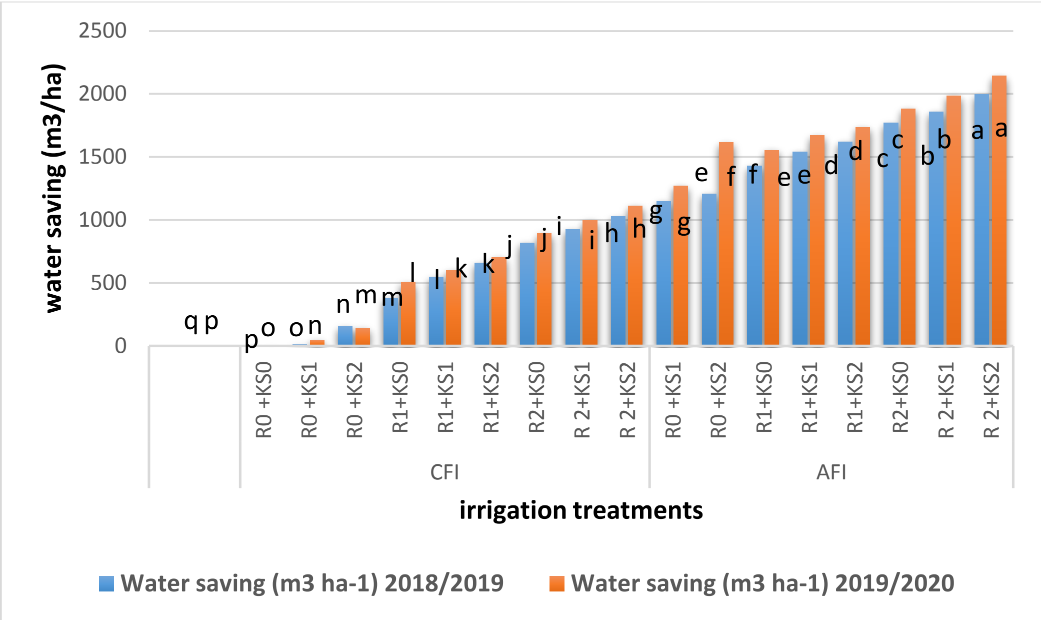

Fig 1. Saved water as affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato plants during winter season of 2018/19.

CFI = conventional furrow irrigation - AFI alternate furrow irrigation) - (R_o= 0, R_1= 6 and R_2= 12 ton ha^{-1} Rabbit Manure) - (KS_0= 0, KS_1= 85 and KS_2= 170 kg K_2O ha^{-1}).

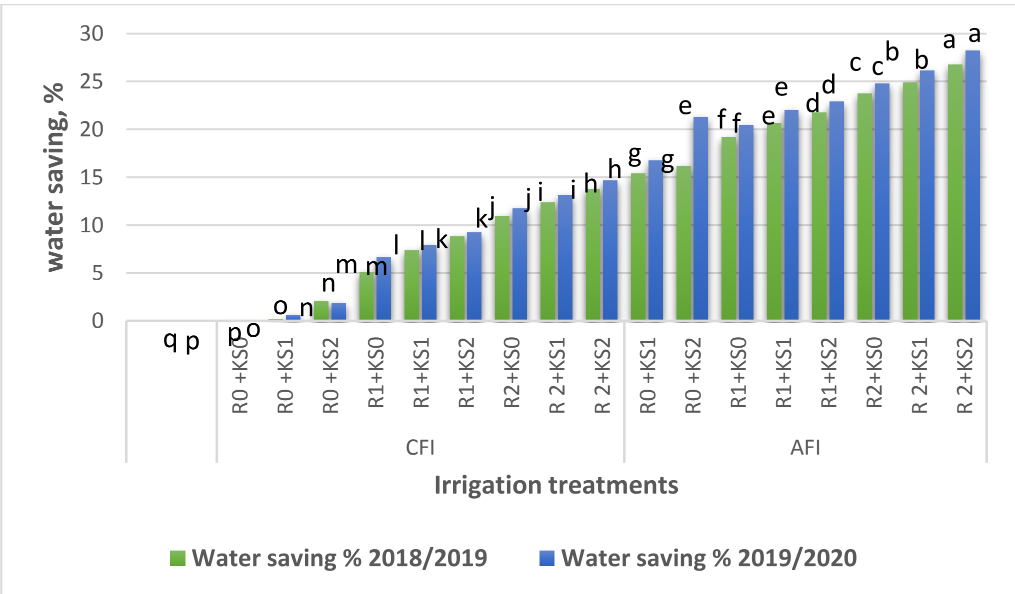

Fig 2. Saved water as affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato plants during winter season of 2019/20.

5- Potato *yield and its nutrients content*

The potato tuber yields were significantly influenced by furrow irrigation and additions of rabbit manure and potassium sulfate Table (6) and represented in Fig (3 and 4). Alternate furrow irrigating (AFI) with R_2+KS_2 gave the highest tuber yield of 37.87 and 38.65 t ha^{-1}in the 1st and 2nd seasons, respectively. Conventional furrow irrigating (CFI) with R_0 +KS_0 realized the lowest tuber yield of 23.56 and 24.15 t ha^{-1} for the corresponding seasons. In accordance with this result, Kassaye et al. (2020) reported that different irrigation methods affected the tuber yield. There was a significant effect of additions of rabbit manure and potassium sulfate. Similar result was acquired by Ahmed et al. (2019), Abd-Elrahman et al (2018), Sakara 2020 and Elglaly et al. (2021) who reported that organic manures application increased tuber yield of potato.

TABLE 6. Tubers Yield and macronutrients content (NPK) that affected by furrow irrigation, rabbit manure and potassium sulfate applications for potato plants during winter season of 2018/19 and 2019/20

Treatments		Tubers Yield (Mg ha^{-1})	nitrogen content (g kg^{-1})	phosphorus content (g kg^{-1})	potassium content (g kg^{-1})
Irrigation systems	rabbit manure and k_2 SO_4	2018/2019		2019/2020	
CFI	R_0 +KS_0	23.56 o	17.67 m	3.67 i	31.45 o
	R_0 +KS_1	26.65 n	18.45 l	3.73 i	34.95 n
	R_0 +KS_2	28.45 l	18.65 l	3.95 h	35.35 m
	R_1+KS_0	28.50 l	20.33 i	4.33 g	36.56 k
	R_1+KS_1	30.75 i	21.23 g	4.67 e	41.45 h
	R_1+KS_2	32.65 g	21.55 f	4.98 c	45.15f
	R_2+KS_0	32.45 g	22.64 d	4.76 d	39.95 j
	R_2+KS_1	33.56 f	23.43 c	5.11 c	45.35 e
	R_2+KS_2	35.35 c	23.87 b	5.34 b	48.35 b
AFI	R_0 +KS_1	26.97 m	19.24 k	3.92 h	35.12 n
	R_0 +KS_2	28.64 k	19.65 j	3.98 h	35.85 l
	R_1+KS_0	29.11 j	20.97 h	4.55 f	37.24 j
	R_1+KS_1	31.35 h	21.54 f	4.85 d	43.15 g
	R_1+KS_2	33.95 f	22.11 e	5.07 c	45.95 d
	R_2+KS_0	34.75 d	22.74 d	5.15 c	40.80 i
	R_2+KS_1	36.82 b	23.76 b	5.36 b	46.48 c
	R_2+KS_2	37.87 a	24.30 a	5.74 a	49.11 a
2019/2020					
CFI	R_0 +KS_0	24.15 l	18.76 k	3.57 g	31.64 n
	R_0 +KS_1	27.25 k	19.34 j	3.63 g	35.24 m
	R_0 +KS_2	28.76 j	19.65 i	3.78 f	35.95 l
	R_1+KS_0	28.98 i	20.44 h	4.39 e	36.85 k
	R_1+KS_1	31.45 g	21.06 g	4.63 de	41.68 g
	R_1+KS_2	33.18 e	23.16 d	4.96 d	45.65 e
	R_2+KS_0	32.87 f	22.55 e	4.86 d	40.23 i
	R_2+KS_1	34.51 d	24.23 c	5.03 cd	45.87 e
	R_2+KS_2	35.88 c	25.84 a	5.22 c	48.68 b
AFI	R_0 +KS_1	27.35 k	19.52 j	4.65 de	35.48 m
	R_0 +KS_2	29.15 i	19.91 i	4.85 d	36.25 l
	R_1+KS_0	29.76 h	20.89 g	4.74 de	37.84 j
	R_1+KS_1	31.65 g	22.12 f	4.90 d	43.65 f
	R_1+KS_2	34.22 d	24.51 c	5.01 cd	46.18 d
	R_2+KS_0	35.45 c	22.97 d	5.13 c	41.25 h
	R_2+KS_1	37.23 b	25.42 b	5.37 b	46.95c
	R_2+KS_2	38.65 a	26.25 a	5.73 a	49.57 a

CFI = conventional furrow irrigation - AFI alternate furrow irrigation) - (R_o= 0, R_1= 6 and R_2= 12 ton ha^{-1} Rabbit Manure) - (KS_0= 0, KS_1= 85 and KS_2= 170 kg K_2O ha^{-1})

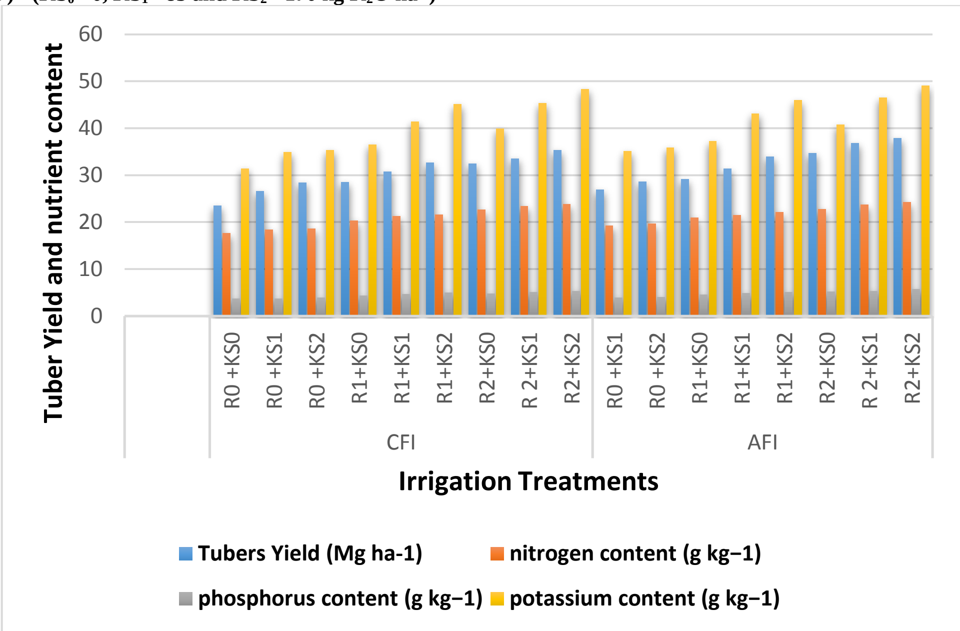

Fig 3. Tubers Yield and macronutrients content (NPK) that affected by furrow irrigation, rabbit manure and potassium sulphate applications for potato plants during winter season of 2018/19.

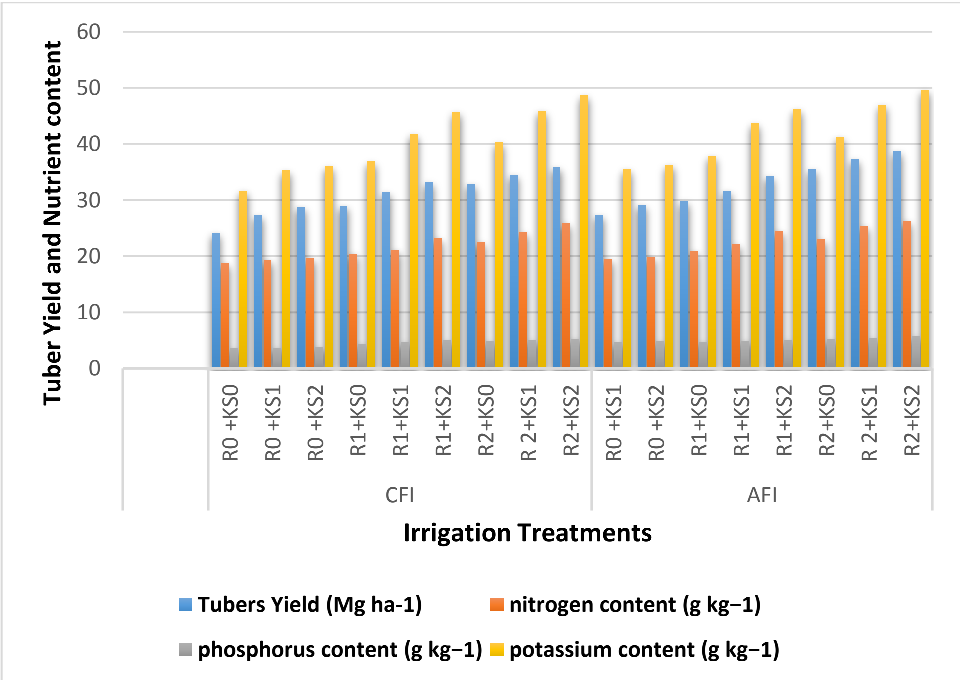

Fig 4. Tubers Yield and macronutrients content (NPK) that affected by furrow irrigation, rabbit manure and potassium sulphate applications for potato plants during winter season of 2019/20.

Nitrogen content of potato was significantly influenced by furrow irrigation and additions of rabbit manure and potassium sulfate Table (6) and Fig (3 and 4). The Alternate furrow irrigation (AFI) with R_{12}+$KS_{100\%}$ gave the highest N content of 24.30 and 26.25 g kg^{-1} in the 1st and 2nd season, respectively. The conventional furrow irrigation (CFI) with R_0 +KS_0 gave the lowest N content of 17.67 and 18.76 g kg^{-1} for the corresponding seasons.

Phosphorus content of potato was significantly influenced by furrow irrigation and additions of rabbit manure and potassium sulfate Table (6). The Alternate furrow irrigation (AFI) with R_{12}+$KS_{100\%}$ attain the highest P content of 5.74 and 5.73 g kg^{-1} in the 1^{st} and 2^{nd} season, respectively. The conventional furrow irrigation (CFI) with R_0 +KS_0 recorded the lowest P content of 3.67 and 3.57 g kg^{-1} for the corresponding seasons.

Potassium content of potato was significantly influenced by furrow irrigation and additions of rabbit manure and potassium sulfate Table (6). The Alternate furrow irrigation (AFI) with R_2+KS_2 gave the highest K content of 49.11 and 49.57 g kg^{-1} in the 1^{st} and 2^{nd} season, respectively. The conventional furrow irrigation (CFI) with R_0+KS_0 gave the lowest K content of 31.45 and 31.64 g kg^{-1} for the corresponding seasons. Similar results were acquired by El-Sayed et al. (2015) and Elglaly et al. (2021).

It might be concluded that practiced the Alternate furrow irrigation (AFI) with R_2+KS_2 achieved the highest tuber yield of potato crop and its quality. Also this management practice of AFI with R_2+KS_2 realized the highest potato water relationships since it recorded the highest crop water productivity (≈ 9.5 kg m^{-3}) and irrigation water productivity (≈ 7 kg m^{-3}) as well as saved high amount of irrigation water (28.23%) that might be used to irrigate other crops.

Conclusions

The water saving ranged from 8.2 to 22.8% for CFI and AFI over two season and the highest values were 14.7 and 28.3% with high level from manure and K fertilizer under CFI and AFI, respectively.

It might be concluded that practiced the alternate furrow as an irrigation system with $R_{12}KS_{100\%}$ achieved the highest potato tuber yield with good quality.

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