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Effect of furrow irrigation patterns and manure level on potato crop water relationships and some soil chemical properties

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Abstract

A field experiment was carried out during the winter seasons of 2018/19 and 2019/20 at The Agricultural Experimental Farm, Faculty of Agricultural, Al-Azhar University, Assiut, Egypt (27º 12- 16.67= N latitude and 31º 09- 36.86= E longitude). The study aims to assess the effect of irrigation patterns (conventional, alternative and fixed furrow irrigation, CFI, AFI and FFI) and rabbit manure application (0, 5 and 10 ton ha^{-1}, R_o, R_5 and R_{10}) on soil chemical properties and potato water relationships and its yield. The experiment was laid out in split plots design with three replicates. The main plots were allocated to irrigation patterns and the split plots were assigned for rabbit manure. The results showed that CFI practice with R_0 realized the highest amount of both water consumptive use (WCU) and irrigation water applied (IWA) through both seasons. While the lowest amount of WCU and IWA were obtained by FFI practices with R_{10} through both seasons. The highest value of irrigation water productivity and crop water productivity were attained by AFI with R_{10} through both seasons. While the lowest Value of irrigation water productivity and crop water productivity were obtained by CFI with R_0 through both seasons. The highest amount of saved water (≈31%) was attained by FFI practices with R_{10} through both seasons compared to CFI with R_0. Generally, soil properties (soil reaction pH, EC, OM, available NPK were positively affected by the application rates of rabbit manure under different irrigation patterns. The tuber yields of potato and N, P, K content was significantly influenced by irrigation patterns and additions rabbit manure. It might be concluded that practiced the fixed furrow as an irrigation pattern with 10 ton h^{-1}, rabbit manure application achieved the highest tuber yield of potato crop and its quality. Also, this management improved soil chemical properties and increased macronutrients availability.

Keywords: furrow irrigation, rabbit manure, water consumptive use, crop water productivity, soil properties, potato yield.

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1. Introduction

Potato crop is one of the most important food crops over worldwide. In Egypt it ranks the fourth most important food crop in terms of its production, after wheat, rice and maize (Shabrawy and Ragab, 2019). Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Kiziloglu *et al*., 2006). Meleha (2002) showed that the highest values of water applied were recorded with the furrow irrigation system while, the lowest values were recorded with bed irrigation system. Potato water use varies with management practices and irrigation levels (Chen *et al*., 2019). Slatni *et al*. (2011) found that the average irrigation amounts were 65, 60, and 91 mm, and the water productivity values amounted to 8.0, 8.7, and 5.9 kg m^{-3} for AFI, FFI and CFI, respectively without yield reduction under AFI. Sarker *et al*. (2019) found that potato tuber yield, tuber quality, and potato water productivity were positively affected by AFI in a raised bed system while potato yield slightly varied between AFI and CFI. Also, AFI practice saved 35% of irrigation water and significantly improved irrigation water productivity by 50% compared to CFI one. The water use efficiency (WUE) of conventional furrow irrigation (CFI) could significantly be improved and substantial amount of water saved without significant yield reduction by renovating to alternate furrow irrigation (AFI) technique (Du *et al*., 2010). To increase soil fertility, farmers have traditionally practiced manure application as fertilizers which improve soil physical and chemical properties, and to some extents have also utilized municipal bio solids and industrial organic wastes. These manures contain quite essential nutrients amount that improve soil fertility and productivity, growth promoting substances like enzymes and hormones (Bhuma, 2001). Stark *et al*. (2007) confirmed that manure application and bio fertilizers increase soil organic matter content as well as improve soil physical, chemical and biological properties. Also, it increases nutrients availability as a result of reducing soil alkalinity. Hence soil organic matter management is necessary as it directly and indirectly affects various chemical, physical, and biological soil properties that affect crop performance. Hadad *et al*. (2015) reported that the organic matter content increased by increasing the levels of applied organic material. Han *et al*. (2016) found that manure application significantly increased available nitrogen, phosphorus and potassium. The study aims to evaluate the influence of different irrigation patterns and rabbit manure applications on soil chemical properties and potato water relationships and its yield.

2. Materials and methods

A field experiment was carried out during the winter seasons of 2018/19 and 2019/20 at The Agricultural Experimental Farm, Faculty of Agricultural, Al-Azhar University, Assiut, Egypt (27° 12- 16.67= N latitude and 31° 09- 36.86= E longitude). The present research work was conducted to study the effect of irrigation patterns (CFI, AFI and FFI) and rabbit manure application (0, 5 and 10 ton ha^{-1})

on soil chemical properties and potato water relationships as well as its yield. The experiment was laid out in split plots design with three replicates and consisted of 9 treatments. The variables were three furrow irrigation patterns, with three rabbit manure applications. The main plots were allocated to furrow irrigation patterns (conventional furrow irrigation, CFI, alternate furrow irrigation, AFI and fixed furrow irrigation, FFI) that were bounded with buffer zone of 2 m width to avoid the horizontal seepage. The split units were assigned for rabbit manure applications (0, 5 and 10 ton ha^{-1}, R_o, R_5 and R_{10}). The experimental plots have an area of 20 m^2 (4 m width × 5 m length). The potato (Cara. cv) were planted on the 10th October of both seasons. Potato plants were harvested 110 days after planting. Potato fertilization was preformed according to the recommended doses of Ministry of Agriculture (285 kg N/ha, 180 kg P_2O_5 ha^{-1} and 170 kg K_2O ha^{-1}). The relevant physical and chemical properties of the investigated area were determined according to Page *et al*. (1982) and Klute (1986) and they 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	15.30	3.80	8.05	80	1.13	4.13	65.21	9.55	345
30-60	13.65	3.43	8.03	79	1.16	4.15	64.50	9.35	350

b- Physical properties										
Depth (cm)	Percentage Sand	Silt	Clay	Texture class	Moisture content × θ v% FC	WP	AW (%)	B_d (g/cm^3)	Inf. rate (cm/h)	HC (m/day)
0-30	22.00	40.50	37.50	Clay loam	40	20.0	20	1.32	0.18	0.07
30-60	25.00	39.00	36.00	Clay loam	38	19.0	19	1.37		

OM = organic matter, pH= soil reaction, SP = saturation percent, ECe = salinity in soil past extract, SAR= sodium adsorption ratio. FC = field capacity, WP = wilting point, AW = available water, Bd= bulk density, HC= hydraulic conductivity.

2.1 Actual consumptive water use (evapotranspiration)

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

$$CU = \{D \times Bd \times (q_2 - q_1)/100\}/p$$

Where: CU = Actual consumptive water use. D = the irrigation soil depth (cm). Bd = bulk density of soil (g/cm^3). q_2 = the percentage of soil moisture at field capacity. q_1 = the percentage of soil moisture before irrigation. P = water density (g/m^3).

Since the density of water is 1 g/cm^3, the bulk density is numerically equal to the relative density as:

Relative density = bulk density / density of water

To obtain the actual water consumptive use, the soil moisture percentage was determined gravimetrically on dry basis just before and 24 hours after irrigation.

2.2 Crop water productivity (CWP)

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

Crop water productivity (kg m^{-3}) = Potato yield (kg ha^{-1}) /water consumptive use (m^3 ha^{-1})

Irrigation water Productivity (kg m^{-3}) = Potato yield (kg ha^{-1}) / the applied irrigation water (m^3 ha^{-1})

2.3 Yield and quality

At harvest time, 4 m^2 (2m × 2m) from each centric area of plot were used to estimate potato yield then converted to yield/ hectar as follows:

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})

One-way analysis of variance (ANOVA) and Duncan's multiple range test was used to determine the statistical significance of the difference between the treatments' effects on soil properties and yield data using CoStat software, and $p < 0.05$ was considered statistically significant. All the results are shown as mean values (n = 3) ± standard deviation (SD).

3. Results and discussion

3.1 Actual evapotranspiration (ET_a) of potato plants through different growth stages

Actual evapotranspiration (ET_a) as affected by different furrow irrigation patterns and rabbit manure applications through the growth stages of potato plants in winter season of 2018/2019 and 2019/2020 is presented in Table (2). The irrigation treatments affected the ET_a in both seasons since the ET_a increased under conventional furrow irrigation (CFI) and Alternate furrow irrigation (AFI) but it decreased by the Fixed furrow irrigation (FFI) in both seasons. The results indicated that ET_a at the different stages slightly increased in winter season of 2019/2020 compared to that of 2018/2019. This may be associated to some factors affecting evapotranspiration such as differences in climatic factors between the two seasons. Since high temperature would automatically result in higher water consumptive use. This trend is in harmony with that obtained by Attia *et al.* (2015), Yang *et al.* (2015) and EL-Sayed, et al. (2020). Also, data in Table (2) demonstrated that the rabbit manure realized an effect on ET_a. The actual evapotranspiration decreased with increasing rabbit manure applications compared to zero addition. The highest value of WCU and IWA under CFI with R_0 were 5146 and 6907.38 m^3 h^{-1}, respectively in the 2nd season (Table 3). The lowest value of WCU and IWA under FFI with R_{10} were 3594.90 and 4770.94 m^3 ha^{-1}, respectively in the 1st season. It was noticed that the increase in WCU and IWA might be due to the rabbit manure applications. The obtained results are consistent with those obtained by Gebremariam *et al*. (2018) and Sarker *et al*. (2019).

Table (2): Actual evapotranspiration (mm) as affected by irrigation furrow and rabbit manure applications for potato crop through growth stages during winter season of 2018/2019 and 2019/2020.

Treatments		Growth stage				Gross season (110 day)
Irrigation patterns	Rabbit manure	Initial (25 day)	Development (40 day)	Mid (20 day)	End (25 day)	
2018/2019						
CFI	R_0	135.25	170.30	92.75	110.50	508.8
	R_5	132.5	165.70	88.40	108.65	495.25
	R_{10}	130.45	163.80	87.60	106.75	488.60
AFI	R_0	117.67	149.01	82.36	96.47	445.51
	R_5	113.95	142.83	76.91	94.20	427.89
	R_{10}	111.53	140.87	75.25	91.06	418.71
FFI	R_0	104.14	131.98	70.95	85.42	392.50
	R_5	99.38	124.61	66.39	82.25	372.62
	R_{10}	96.53	119.57	64.39	79.00	359.49
2019/2020						
CFI	R_0	137.35	171.25	93.70	112.30	514.60
	R_5	133.00	167.65	89.80	109.90	500.35
	R_{10}	131.50	164.50	87.90	107.45	491.35
AFI	R_0	119.42	151.50	83.60	97.00	451.52
	R_5	115.20	144.00	77.80	95.40	432.40
	R_{10}	112.25	141.75	75.95	92.70	422.65
FFI	R_0	106.32	132.80	71.86	87.33	398.31
	R_5	99.85	125.55	67.25	82.00	374.65
	R_{10}	96.85	120.42	64.87	80.32	362.46
	R_{10}	96.85	120.42	64.87	80.32	362.46

3.2 Crop water productivity and irrigation water productivity

Crop water productivity (CWP) and irrigation water productivity (IWP) as affected by furrow irrigation patterns and rabbit manure applications for potato plants in winter season of 2018/2019 and 2019/2020 is presented in Table (3). The irrigation treatments affected CWP and IWP through both seasons since they were increased under AFI and FFI practices, but they decreased under CFI through both seasons. The highest values of CWP (9.07 kg/ m^3) and IWP (6.88 kg m^{-3}) were recorded under AFI with R_0 in the 2^{nd} season. The lowest values of CWP (4.95 kg m^{-3}) and IWP (3.68 kg m^{-3}) were recorded under CFI with R_{10} in the 1^{st} 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) and fixed furrow irrigation (FFI) are suitable to achieve high potato production with minimum water applied. These results are consistent with those obtained by Gebremariam *et al*. (2018) and Sarker *et al*. (2019).

Table (3): Water consumptive use, irrigation water applied, crop water productivity and irrigation water productivity that affected by furrow irrigation patterns and rabbit manure applications for potato crop during winter season of 2018/2019 and 2019/2020.

Treatment			Water consumptive use (m^3 ha^{-1})	Irrigation water applied (m^3 ha^{-1})	Crop water productivity (kg m^{-3})	Irrigation water productivity (kg m^{-3})
Irrigation patterns	Rabbit manure	Tubers Yield (Mg ha^{-1})				
2018/19						
CFI	R_0	25.19 h	5088.00	6847.91	4.95	3.68
	R_5	32.64 d	4952.50	6674.53	6.59	4.89
	R_{10}	35.52 b	4886.00	6567.20	7.27	5.41
AFI	R_0	26.82 g	4455.10	5924.34	6.02	4.53
	R_5	33.80 c	4278.90	5652.44	7.90	5.98
	R_{10}	37.68 a	4187.10	5549.50	9.00	6.79
FFI	R_0	23.98 i	3925.00	5224.97	6.11	4.59
	R_5	30.00 f	3726.20	4939.94	8.05	6.07
	R_{10}	31.67 e	3594.90	4770.94	8.81	6.64
2019/2020						
CFI	R_0	25.63 h	5146.00	6907.38	4.98	3.71
	R_5	32.97 d	5003.50	6698.13	6.59	4.92
	R_{10}	36.11 b	4913.50	6582.05	7.35	5.49
AFI	R_0	27.54 g	4515.20	5980.40	6.10	4.61
	R_5	34.64 c	4324.00	5696.97	8.01	6.08
	R_{10}	38.33 a	4226.50	5572.18	9.07	6.88
FFI	R_0	24.34 i	3983.10	5257.52	6.11	4.63
	R_5	30.83 f	3746.50	4945.87	8.23	6.24
	R_{10}	32.40 e	3624.60	4778.64	8.94	6.78

3.3 The saved water and water distribution efficiency

Data in Table (4) show that the high amount of saved water (2128.74 m^3 ha^{-1}) was recorded under fixed furrow irrigation (FFI) with R_{10} in the 2nd season compared to conventional furrow irrigation (CFI). The saved water % and water distribution % were about 30.82 and 77.23%, respectively compared to conventional furrow irrigation (CFI). 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 and FFI might be due to the lowest area of spreading irrigation water and the lowest wetted area by this manner compared to that under CFI method (Ahamd *et al*., 2011; Ahmad *et al*., 2009; FAO, 2016; Sarker *et al*., 2016; El-Sayed *et al*., 2020).

3.4 Soil chemical properties

Generally, soil properties (pH, EC and OM) were positively affected by rabbit manure application rates under different furrow irrigation patterns (Table 5). Soil reaction (pH) slightly decreased with increasing rabbit manure application rate. Furrow irrigation patterns did not show any significant effect on Soil pH. This illustrates that soil buffering capacity resists the changes in soil reaction (pH) and adding organic materials preserves or improves soil pH (Butler *et al*., 2008; Soheil *et al*., 2012).

Table (4): Saved water and water application efficiency that affected by furrow irrigation patterns and rabbit manure application for potato plants during winter season of 2018/2019 and 2019/2020.

Treatment		Saved water (m^3 ha^{-1})	Saved water (%)	Water distribution efficiency (%)
Irrigation patterns	Rabbit manure			
2018/2019				
CFI	R_0	0	0	75.00
	R_5	173.39	2.53	75.25
	R_{10}	280.71	4.10	76.00
AFI	R_0	923.58	13.49	76.2
	R_5	1195.47	17.46	76.80
	R_{10}	1298.41	18.96	77.10
FFI	R_0	1622.94	23.70	76.00
	R_5	1907.97	27.86	76.45
	R_{10}	2076.98	30.33	77.00
2019/2020				
CFI	R_0	0	0	75.50
	R_5	209.26	3.03	75.85
	R_{10}	325.33	4.71	76.50
AFI	R_0	926.99	13.42	76.50
	R_5	1210.41	17.52	77.12
	R_{10}	1335.20	19.33	77.65
FFI	R_0	1649.86	23.89	76.14
	R_5	1961.51	28.40	76.75
	R_{10}	2128.74	30.82	77.23

On the other side, soil salinity increased by increasing rabbit manure application rates. The EC values ranged between 1.15 -1.35 dSm^{-1}. The highest EC value was recorded under FFI with R_{10} (Table 5). Furrow irrigation methods did not show any significant effect on soil salinity. Many investigators stated that the application of organic materials caused a significant increase in EC in the tested soil (Abdeen and El-Sayed, 2021; Dadhich *et al.,* 2011; Sarwar *et al*., 2010). Soil organic matter (OM) increased by increasing rabbit manure application rates. The OM values ranged between 17.29 -23.05 g kg^{-1}. The highest OM value was recorded under FFI with R_{10} (Table 5). Furrow irrigation methods did not show any significant effect on soil organic matter. These findings are in accordance with those obtained by Urbaniak *et al*. (2017) who found that application of organic resources improved soil chemical properties.

3.5 Available macronutrients

3.5.1 Available nitrogen (N)

The effects of different furrow irrigation patterns and adding rabbit manure during two seasons on nitrogen availability are shown in Table (6). Generally, the results clearly showed that the treatments significantly increased nitrogen availability. The values of available N ranged between 65.45 and 98.96 ppm. The highest value of available N was recorded under FFI with R_{10} in the second season.

Table (5): Soil reaction, Soil salinity and Soil organic matter that affected by furrow irrigation patterns and rabbit manure for potato plants during winter season of 2018/2019 and 2019/2020.

Treatment		Soil reaction (pH)	Soil salinity (dS/m)	Soil organic matter (g/kg)
Irrigation patterns	Rabbit manure			
2018/2019				
CFI	R_0	8.04 a	1.15 d	17.54 f
	R_5	7.91 b	1.20 c	19.85 c
	R_{10}	7.72 c	1.27 b	22.65 a
AFI	R_0	8.02 a	1.20 c	17.45 e
	R_5	7.90 b	1.26 b	20.21 b
	R_{10}	7.71 c	1.30 b	22.75 a
FFI	R_0	8.01 a	1.19 c	17.82 d
	R_5	7.86 b	1.32 a	20.34 b
	R_{10}	7.70 c	1.35 a	22.82 a
2019/2020				
CFI	R_0	8.06 a	1.16 c	17. 29 h
	R_5	7.90 b	1.19 c	19.76 e
	R_{10}	7.74 c	1.25 b	22.76 b
AFI	R_0	8.03 a	1.17 c	17.66 g
	R_5	7.91 b	1.24 b	20.27 d
	R_{10}	7.74 c	1.29 a	22.98 a
FFI	R_0	8.02 a	1.20 b	17.87 f
	R_5	7.84 b	1.28 a	20.50 c
	R_{10}	7.75 c	1.32 a	23.05 a

The lowest value of available N was attained under CFI with R_0 in the first season. It is noticed that increasing available nitrogen might be due to the adding rabbit manure. These results agree with Shehata *et al*. (2014) and Bakr (2016) who reported that adding organic fertilizer to soil improve its physical-chemical and biological properties which increase soil organic matter, available mineral nutrients.

Table (6): Available macronutrients (NPK) that affected by furrow irrigation patterns and rabbit manure for potato plants during winter season of 2018/2019 and 2019/2020.

Treatment		Available nitrogen (ppm)	Available phosphorus (ppm)	Available potassium (ppm)
Irrigation patterns	Rabbit manure			
2018/2019				
CFI	R_0	65.45 h	10.57 d	350.25 f
	R_5	81.56 f	11.23 b	371.12 d
	R_{10}	95.65 c	12.45 a	390.75 b
AFI	R_0	66.75 g	10.85 c	353.34 e
	R_5	83.35 e	11.35 b	375.52 c
	R_{10}	96.75 b	12.52 a	394.54 a
FFI	R_0	66.91 g	10.91 c	352.76 e
	R_5	84.55 d	11.37 b	378.67 c
	R_{10}	97.45 a	12.62 a	394.12 a
2019/2020				
CFI	R_0	66.21 h	10.43 d	354.65 d
	R_5	82.12 f	11.25 b	373.65 c
	R_{10}	96.34 c	12.52 a	393.95 a
AFI	R_0	67.59 g	10.76 c	355.45 d
	R_5	83.34 e	11.28 b	376.15 b
	R_{10}	97.13 b	12.45 a	397.34 a
FFI	R_0	67.91 g	10.84 c	353.95 d
	R_5	85.47 d	11.33 b	375.75 b
	R_{10}	98.96 a	12.65 a	395.86 a

3.5.2 Available phosphorus (P)

The effects of different furrow irrigation patterns and adding rabbit manure during two seasons on phosphorus availability are shown in Table (6). Generally, the results clearly showed that the treatments significantly increased the concentration of available phosphorus. The P values ranged between 10.34 and 12.65 ppm. The highest P value was recorded under FFI with R_{10} in the second season. The lowest P value was attained under CFI with R_0 in the second season. The increase in available phosphorus might be due to the addition of rabbit manure. Similar result was obtained by Hadad *et al*. (2015) who reported that available phosphorus increased by increasing organic wastes levels from 5 to 30 ton/feddan (feddan = 4200 m² = 0.420 hectares = 1.037 acres).

3.5.3 Available potassium (K)

The effects of different furrow irrigation patterns and additions of rabbit manure during two seasons on potassium availability are shown in Table (6). Generally, the results clearly showed that all the treatments significantly increased the concentration of available potassium. The K values varied from 350.25 to 395.86 ppm. The highest K value was recorded under FFI with R_{10} in second season. The lowest K value was attained under CFI with R_0 in the second season. Also, the increase in available potassium might be due to the addition of rabbit manure. These results are compatible with those of Shehata *et al*. (2014) and Bakr (2016) who reported that adding organic fertilizer to soil improve its physical-chemical and available nutrients.

3.6 Potato yield and its nutrients content.

The tuber yields of potato were significantly influenced by furrow irrigation patterns and additions of rabbit manure (Table 7). Alternate furrow irrigating (AFI) with 10 ton/ ha. rabbit manure (R_{10}) gave the highest tuber yield of 37.68 and 38.33 t ha^{-1} in the 1st and 2nd seasons, respectively. Fixed furrow irrigating (FFI) with R_0 realized the lowest tuber yield of 25.19 and 25.63 t ha^{-1} for the corresponding seasons. In accordance with this result, Kassaye *et al*. (2020) reported that different furrow irrigation methods affected the tuber yield. There was a significant effect of rabbit manure application levels. Similar result was acquired by Ahmed *et al*. (2019) who reported that organic manures application increased tuber yield of potato. Nitrogen content of potato was significantly influenced by furrow irrigation patterns and additions of rabbit manure (Table 7). The fixed furrow irrigation (FFI) with R_{10} gave the highest N content of 23.45 and 23.55 g kg^{-1} in the 1st and 2nd season, respectively. The conventional furrow irrigation (CFI) with R_0 gave the lowest N content of 18.35 and 18.18 g kg^{-1} for the corresponding seasons. Phosphorus content of potato was significantly influenced by furrow irrigation patterns and additions of rabbit manure (Table 7). The fixed furrow irrigation (FFI) with R_{10} gave the highest P content of 5.76 and 6.10 g kg^{-1} in the 1st and 2nd season, respectively. The conventional furrow irrigation (CFI) with R_0 recorded the lowest P content of 3.53 and 3.60 g kg^{-1}

for the corresponding seasons. Potassium content of potato was significantly influenced by furrow irrigation patterns and additions of rabbit manure (Table 7).

Table (7): Tubers Yield and macronutrients content (NPK) that affected by furrow irrigation patterns and rabbit manure for potato plants during winter season of 2018/2019 and 2019/2020.

Treatment		Tubers yield ($Mg\ ha^{-1}$)	Nitrogen content ($g\ kg^{-1}$)	Phosphorus content ($g\ kg^{-1}$)	Potassium content ($g\ kg^{-1}$)
Irrigation patterns	Rabbit manure				
2018/2019					
CFI	R_0	25.19 h	18.35 h	3.53 f	22.12 g
	R_5	32.64 d	20.15 e	4.45 d	24.86 d
	R_{10}	35.52 b	22.27 b	4.95 c	26.25 bc
AFI	R_0	26.82 g	18.64 g	3.75 f	23.15 f
	R_5	33.80 c	20.54 d	4.93 c	25.11 d
	R_{10}	37.68 a	22.55 b	5.37 b	26.80 b
FFI	R_0	23.98 i	19.25 f	4.05 e	23.65 e
	R_5	30.00 f	21.25 c	5.23 b	25.85 c
	R_{10}	31.67 e	23.45 a	5.76 a	27.22 a
2019/2020					
CFI	R_0	25.63 h	18.18 i	3.60 e	22.65 h
	R_5	32.97 d	20.43 f	4.59 d	25.10 e
	R_{10}	36.11 b	22.19 c	5.10 c	26.87 c
AFI	R_0	27.54 g	18.75 h	3.67 e	23.95 g
	R_5	34.64 c	20.92 e	4.95 c	25.75 d
	R_{10}	38.33 a	22.85 b	5.72 b	27.10 b
FFI	R_0	24.34 i	19.65 g	4.21 d	24.25 f
	R_5	30.83 f	21.45 d	5.54 b	27.54 b
	R_{10}	32.40 e	23.55 a	6.10 a	28.15 a

The fixed furrow irrigation (FFI) with R_{10} gave the highest K content of 27.22 and 28.15 g kg^{-1} in the 1st and 2nd season, respectively. The conventional furrow irrigation (CFI) with R_0 gave the lowest K content of 22.12 and 22.65 g kg^{-1} for the corresponding seasons. Similar result was acquired by El-Sayed *et al*. (2015). It might be concluded that practiced the fixed furrow as an furrow irrigation pattern with 10 ton/ ha^{-1}. rabbit manure application achieved the highest tuber yield of potato crop and its quality. Also, this management (FFI with R_{10}) realized the highest potato water relationships since it recorded the highest crop water productivity (≈ 9 kg/ m^3) and water distribution efficiency (77%) as well as saved high amount of irrigation water (30%) that might be used to irrigate other crops. In addition, fixed furrow irrigation with 10 ton/ ha^{-1}. rabbit manure application improved soil chemical properties (pH, EC and OM) and increased macronutrients (NPK) availability.

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