MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
ISSN-Print: 1687-384X
ISSN-Online: 2636-3062

Misr J. Ag. Eng., 39 (2): 185 – 204
DOI:10.21608/mjae.2022.111140.1058

ASSESSING THE IMPACTS OF IRRIGATION SYSTEMS AND VARIOUS RATES OF MINERAL AND BIO-FERTILIZERS ON YIELD AND WATER USE EFFICIENCY OF POTATOES

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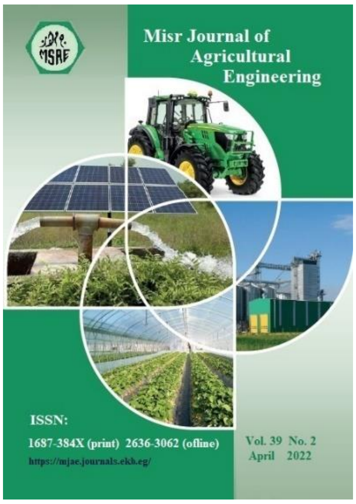

Keywords:
Irrigation system; Potatoes; Mineral fertilization; Bio-fertilization; Water productivity.

ABSTRACT

An experimental field trial was conducted at Wadi El Natrun Beheira Province, Egypt (latitude of 30.42 ˚ N and longitude of 30˚.33E) during two successive growing seasons of 2019 and 2020. The study aimed to evaluate the effects of irrigation systems and different rates of mineral and bio-fertilizers on the yield and water use efficiency of potatoes. The field trial was arranged in a split-plot design with two irrigation systems (drip; I_1) and micro-sprinkler (I_2), three rates of mineral fertilizer (100, 75, and 50% of MF) alone or plus biofertilizer (BF) where BF consisted of (Azoasperilum +Bacillus megaterium) and two potato cultivars (Bellini C_1 and Arizona C_2). The results showed significant differences for growth and yield characteristics of the interaction between I_1 ,100% MF or (100 MF+ BF) and C_1 or C_2 cultivars) for leaf area - productivity – and grading (Y_4), as well as the content of leaves from nitrogen and phosphorous during the two growing seasons. There were significant differences for the interaction I_2 + C_1 + 50% MF in the grading trait (Y_3) only. The interaction (I_1 or I_2 + C_1 or C_2 + 75% MF) was equal in achieving the highest significant results for the grading (Y_5). It is recommended that the I_1 + C_1 or C_2 + 100% MF+BF treatment is the optimum one for potato grown under field conditions, as the drip irrigation system provided the amount of water and a significant increase in most growth characteristics of potatoes compared to micro-sprinkler irrigation.

1. INTRODUCTION

In potato cropping systems, water and nitrogen availability are critical for controlling output levels, especially in arid and semi-arid environments. Water scarcity and rising irrigation expenses, as well as high fertilizer prices, have prompted farmers to implement measures that enhance water and nitrogen usage efficiency. In 2019, global potato production was estimated at 370.4 million Mg on approximately 17.34 million hectares, with 45.1 million Mg on approximately 1.54 million hectares in the Americas; 107.26 million Mg on approximately 4.7 million hectares in Europe, 1.74 million Mg on approximately 43,303 ha in Oceania, 189.81 million Mg on approximately 9.30 million hectares in Asia, and 26.53 million Mg on approximately 1.76 million hectares in Africa (**FAOSTAT 2019**). Potato production in Egypt during the 2019 season was 5.1 million Mg on 289926 hectares (**FAOSTAT 2019**). Potatoes are one of the most water-efficient crops, delivering the highest calories per unit of water intake (**Vreugdenhil et al., 2011**). It is also one of the most significant food crops which can be used as a low-cost energy source in human nutrition. Moreover, it is a low-cost food that's abundant in starch, minerals, vitamins C and B, and amino acids, and it's well-liked worldwide (**Van Der Zaag and Horton 1983**). If efficient and dependable irrigation management systems are used to maintain adequate moisture in the effective root zone, potato growing could be a viable option for increasing farm income. It is best accomplished by employing contemporary irrigation systems in conjunction with appropriate irrigation scheduling in areas with limited water supplies, particularly in semi-arid environments (**Spieler 1994**). Water efficiency enables the utilization of more arable land and the production of agricultural crops. As a result, using new irrigation techniques with great efficiency is crucial to increase productivity and ensure enough food supply. Because of their high overall effectiveness and lack of fertilizer and water losses, fertilization with irrigation is an essential way to rationalize fertilizer usage (**Mostafa, Derbala 2013; Mostafa 2014**). Under potato production, several irrigation methods such as sprinkler, furrow, surface drip, and subsurface drip irrigation were used with varying results depending on the local climate and soil condition, with contrasting findings in some research. **Onder et al. (2005**) tested surface and subsurface drip irrigation with four irrigation regimes: 0, 33, 66, and 100% full irrigation and found that irrigation systems had no significant effect on tuber yield. Surface drip irrigation, on the other hand, had the highest water use efficiency and therefore be recommended for potato cultivation in Mediterranean conditions (**Weatherhead, and Knox 1998, Onder et al. 2005**). Potato tuber productivity and quality can be improved by combining contemporary irrigation systems with a proper watering schedule. For potato crop output and economics, drip or sprinkler irrigation is considered a superior option to traditional floods irrigation methods (**Pawar et al., 2002; Pawar and Dingre, 2014 and 2020**).

Because nitrogen fertilizer is essential for normal plant and tuber development, potato growth is characterized by a high demand for it (**Waddell et al., 1999**). However, applied water and fertilizer are at risk of leaking below the root zone due to a shallow (about 30 cm) and inefficient root system (**Satchithanantham et al., 2014; Zotarelli et al., 2015**). Despite their high value, fertilization expenses may have a negative impact on potato profitability (**Ierna et al., 2011**). Due to the expensive cost of mineral fertilization, which is also associated with environmental damage (when used incorrectly), biofertilizers, which are vaccinations containing some living microorganisms, have become popular. Where the effectiveness of some microorganisms and their vital activity can be utilized and harnessed optimally by pollinating seeds with microorganisms, as they work to stabilize nitrogen, melt phosphorus and potassium, and produce hormones stimulating growth, amino acids, and vitamins that improve soil properties, resulting in increased crop productivity. Bio-fertilizers play a vital role in enhancing nutrient availability by reducing the degree of interaction through the production of organic acids, as well as creating phytohormones and antibiotics to protect themselves and the plant against bacterial and fungal infections (**Vessey 2003**).

Microorganism-derived bio-fertilizers can be used instead of chemical fertilizers to boost crop yields. Biofertilizers are, on the whole, cheaper and more environmentally benign than chemical fertilizers. The advantages of employing biofertilizers are widely established, in addition to their role in reducing the use of chemical fertilizers (**Yazdani et al. 2009; Eid and El-Sayed 2012**). Pseudomonas, Azospirillum, Azotobacter, and Bacillus are among the most commonly utilized growth-promoting bacteria in several recent studies **(Alsaady et al. 2020; Prasad and Babu 2017)**. In addition to nitrogen fixation, Azospirillum stimulates root growth by generating growth stimulants, which increase water and nutrient intake, producing higher yields (**Tilak et al. 2005).** Pseudomonas fluorescens is one of the most significant bacteria, and the positive benefits of their inoculation on growth have been demonstrated **(Paszt et al. 2011).** In general, increasing the quantity and diversity of microorganisms, as well as microbial community interactions, increases the amount and variety of organic acids that are useful in the process of dissolving insoluble phosphates **(Srivastava et al. 2010).** Among the primary food crops, potatoes have been shown to have a high-water use efficiency (WUE) ranging from 6 to 11.6 kg/ha/m^3 (**FAO,2020**). Potato WUE, on the other hand, is heavily influenced by genetic material, management strategies, irrigation regime, fertilizer rate, and other environmental factors. Modern potatoes have a high WUE, however, they are not as economically productive as heritage potatoes when grown with the same amount of water (**Fandika et al. 2016**). In New Zealand, they discovered potatoes with WUE ranging from 5.2 to 11.8 kg/ha/m^3 under irrigation, 9.0 to 12.9 kg/ha/m^3 under rain-fed cultivation, and 8.3 kg/ha/m^3 under 80 kg N/ha and 7.0 kg/ha/m^3 under 240 kg N/ha. As a result, higher irrigation regimens and nitrogen application rates reduced WUE. The overall aim of this research study was to evaluate the effects of irrigation systems and different rates of mineral and bio-fertilizers on the yield and water use efficiency of potatoes.

2. MATERIALS AND METHODS

The experiment's site, circumstances, design, and agronomic techniques

During the 2019 and 2020 growing seasons, two field trials on a drip and micro-sprinkler-irrigated potato crops were done at a private farm for the Dakahlia Agricultural Development Company in Wadi El Natrun, Beheira Governorate, Egypt (30 ˚.42$^/$ N and 30˚.33$^/$ E). An arid climate with mild cold winters and warm summers characterized the experimental site settings. The precise environmental conditions of the Wadi El Natrun region over the experimental periods are shown in Table 1. The soil at the study site is sandy loam in texture (79.8% sand, 15.4 % silt, and 4.8% clay); bulk density, electrical conductivity (EC), field capacity, wilting point, and available water content of 1.48 g cm^{-3}, 1.25 dS m^{-1}, 0.2678 m^{-3}m^{-3}, 0.1349 m^{3}m^{-3}, and 0.1225 m^{3}m^{-3}, respectively. In addition, the salinity of water (EC) used for irrigation was 1.23 dS m^{-1}.

The experiments in both growing seasons were laid out in a split-plot design with three replicates. Tow irrigation systems (drip (I_1) and micro-sprinkler (I_2) irrigation systems), two potato varieties (Bellini (C_1) and Arizona (C_2)) and three rates of mineral fertilizers (100, 75, and 50% of MF) alone and plus biofertilizer (BF) where BF consisted of (*Azoasperilum* +*Bacillus megaterium*) were evaluated in this research study. The irrigation systems and different cultivars were distributed randomly in the main plots and the sub-plots, respectively.

Table (1): Wadi El Natrun meteorological data, as well as varied amounts of water applied under tested irrigation systems in the 2019 and 2020 growing seasons

Year	Month	T_{max}, (ºC)	T_{min}, (ºC)	$T_{average}$, (ºC)	RH (%)	ETo (mm)	Rainfall (mm)	Applied water, mm	Applied water, mm
								100% ETc (drip)	100% ETc (micro-sprinkler)
2019	November	23.1	11	17.05	67.1	6.02	12	110	140
	December	20.7	9.3	15	65.2	5.1	10.2	140	170
	January	19.7	8.1	13.9	64.1	5.2	5.7	180	210
	February	24.5	7.98	16.24	60.5	6.7	4.5	80	100
							Total	**510**	**620**
2020	November	24.3	12.2	19.05	66.2	6.03	11	110	140
	December	22.6	11.3	17	64.2	5.2	11.2	140	170
	January	18.7	7.9	13.2	63.1	5.1	5.6	180	210
	February	23.5	8.98	15.24	61.5	6.5	4.3	80	100
							Total	**510**	**620**

T_{max}, T_{min}, T_{avarag}, RH, and ET_o, indicate maximum temperature, minimum temperature, average temperature, relative humidity and reference evapotranspiration respectively

The irrigation systems (drip and micro-sprinkler) were divided into two main sectors, each sector divided into 12 longitudinal lines, and each line of 50m long was divided into two parts, each part 25m long representing three replicates. So that every two lines represent a treatment of the experiment as shown in figure (1). All irrigation systems, fertilization added treatments, and cultivars were randomly distributed in each sector. The irrigation system within each sector consisted of 24 polyethylene lateral drip lines for the main plots (16 mm in diameter), with four lateral drip lines assigned to each cultivar for the sub-plots. The lateral drip lines (50 m long with emitters spaced at 0.30 m apart) were placed along each cultivar row, separated 0.75 m. The drippers had a discharge rate of 4 l h^{-1}. Micro-sprinkler irrigation (I_2) was the second approach; the same methods were utilized for laterals, but they were (8 L/h each with a 2.5 m wet diameter as illustrated in Figure 1. The sub-plot area within each irrigation system was 90.0 m^2. Healthy potato tubers of uniform size from each cultivar were planted around each dripper on November 1, 2019, and 2020, and were dug out on February 18 on both growing seasons.

All treatments received 75 m^3 ha^{-1}, 200 kg ha^{-1}, and 300 kg ha^{-1} of composted animal manure, phosphorous, and sulfur, respectively. The total dose of these fertilizers was applied to the soil during the preparation for planting. 100, 75, and 50% of Phosphorus and sulfur fertilizers were applied in the form of single furrow-banded calcium superphosphate (15.5 % P_2O_5) and elemental S, respectively. Also 100, 75, and 50% of Nitrogen fertilization were applied at a rate of 400 kg ha^{-1} of ammonium nitrate (33.5 % N) in four equal doses.

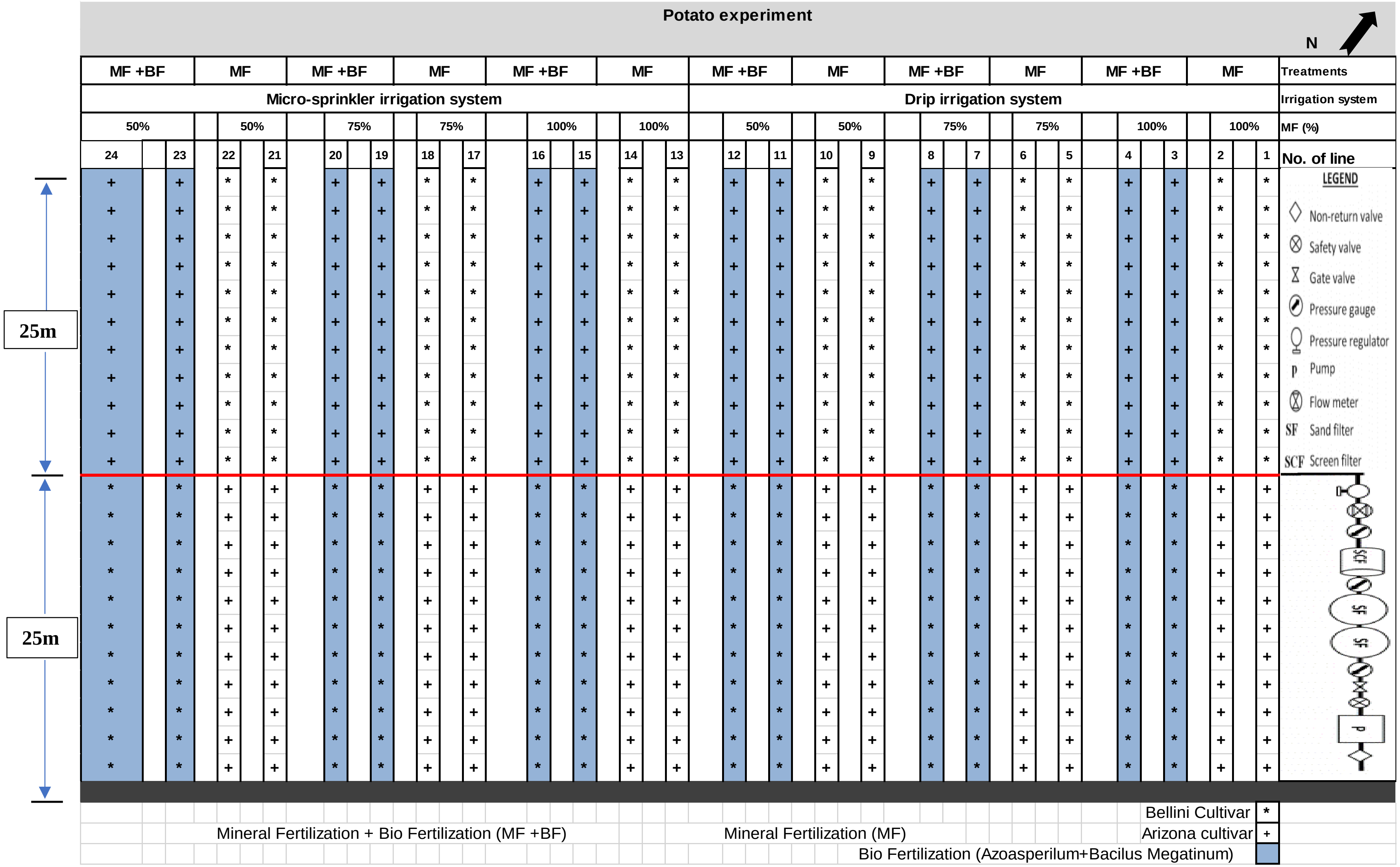

Figure (1): Layout of drip irrigation (I_1) and micro-sprinkler irrigation (I_2) experimental treatments and replicates

The first dose was applied during soil preparation, while the other three doses were applied at 30, 45, and 60 days after planting through the fertigation unit. Potassium fertilization was done by applying 100 kg ha^{-1} of potassium sulfate in two equal doses. The first dose was applied during soil preparation, while the second dose was applied through the fertigation unit with the third dose of the nitrogen fertilizer. The employed biological fertilizer, which contains phosphorin and Microbin, was made in the Microbiological Laboratory. Bacillus megatherium var. phosphaticum is present in the phosphorin inoculants, while Microbin contains four bacteria: Azospirillum brasilienses, Azotobacter vienlandi, Bacillus megatherium var. phosphaticum, and Pseudomonas aurantiaca. The bio-fertilizer was applied in two doses, the first immediately following cultivation and the second after 40 days from planting. The bio-fertilizer was applied at a rate of 100ml/plant (200 g powder/100 L water, as per the instructions).

Water consumption

To determine the irrigation time and calculate the amount of water applied for the complete irrigation regime, the FAO CROPWAT program v.8 was utilized (100 percent ETc). Using the modified FAO Penman-Monteith equation given by **Allen et al. (1998),** this software calculates the reference evapotranspiration (ETo). The ETo in mm day^{-1} was estimated using the several daily environmental indicators gathered from the nearest meteorological station (Table 1). Relative humidity data obtained were used to alter the potato crop coefficient (Kc) the ETc to ETo ratio. The following calculation was used to compute the water required for the 100 % ETc treatment using the ETo and Kc values:

$$ETc = ETo \times Kc. \qquad (1)$$

After calculating the water consumption of the crop, it is multiplied by the reciprocal of the efficiency according to the irrigation system used as presented in table (1).

Water-use efficiency (WUE) and irrigation water-use efficiency (IWUE):

Water-use efficiency (WUE) and irrigation water-use efficiency (IWUE) values were calculated using Eqs. (2) and (3) **(Bhattarai et al., 2006).**

$$WUE = \left(\frac{Ey}{Et}\right) \times 100 \qquad (2)$$

Where WUE is the water use efficiency (kg m^{-3}); Ey is the economical yield (Mg. ha^{-1}); Et is the plant water consumption, (m^3ha^{-1}).

$$IWUE = \left(\frac{Ey}{Ir}\right) \times 100 \qquad (3)$$

Where IWUE is the irrigation water use efficiency (kg m^{-3}), Ey is the economical yield (Mg. ha^{-1}), Ir is the amount of applied irrigation water (m^3ha^{-1}).

Data collected

Parameters of vegetative plant growth:

After 75 days from planting in both seasons, a random sample of 6 plants was selected from each experience replicate to determine the following parameters:

Morphological traits: plant height (cm), leaves and tubers/plant, as well as leaf area/plant (cm^2).

Leaf mineral content: The dry leaves were finely crushed and wet digested for N and P determination 75 days after planting. **Bremner and Mulvaney (1982); Olsen and Sommers (1982)** presented methods for determining the major components (N, P, K, and Ca).

Tuber Yield and its Components: Tubers from each experimental replication were weighed, counted, and classified into three sizes at harvest time (115 days after planting), according to specifications for potato exportation: Grade 1 (Y_5) tubers with a diameter greater than 50 mm, Grade 2 (Y_4) tubers with a diameter between 35 and 50 mm, and Grade 3 (Y_3) tubers with a diameter less than 30 mm were weighed individually. In addition, the following data were gathered: Number of tubers/plants, average tuber weight (g), tuber yield per plant (g), yield of grades 1, 2, and 3, marketable yield (grades 1 + 2), total yield (grades 1 + 2 + 3) Mg/ha., and relative total yield (grades 1 + 2 + 3) Mg/ha (percent).

Statistical analysis:

Based on the co-state software computer system program for statistics, the generated data were subjected to analysis of variance (ANOVA). According to **Steel and Torrie (1984),** the LSD test value was employed to examine differences between treatment means at 0.05 probability level utilizing Duncan's multiples range test for presenting of data.

3. RESULTS AND DISCUSSION

Effect of irrigation systems:

Vegetative growth characteristics:

During the 2019 and 2020 growing seasons, a significant superiority of drip irrigation system over micro-sprinkler irrigation was observed for vegetative growth parameters of potato crop: Y_1 (leaf area at 90day (cm^2), Y_2 (production (Mg/ha), Y_4(Potato Size > 30mm and < 50mm (%), Y_6(N content in potato leaves mg/g), and Y_7(P content in potato leaves mg/g). once exception was noticed showing significant superiority of micro-sprinkler over drip irrigation in Y_3 (Potato Size < 30mm (%) only during both studied seasons. Also, no significant differences between drip and micro-sprinkler irrigation in Y_5 (Potato Size > 50mm (%), during the two, studied seasons as shown in Tables 2 and 3. This could be related to the homogeneous distribution of moisture in the effective root zone of potato observed with drip irrigation in the soil profile. The obtained results are in agreement with these findings obtained by **Ünlü et al. (2006); Yavuz et al., 2012 and Darwish et al., (2021).**

Effect of cultivars:

Vegetative growth characteristics:

Data are shown in Tables 2 and 3 revealed highly significant differences for Bellini cultivar as compared with Arizona cultivar for Y_3 (Potato Size < 30mm (%) only during studied seasons, Y_5 (Potato Size > 50mm (%) during season 2019, and Y_7(N in Potato leaves mg/g) during season 2020. While Arizona cultivar was highly significant different values as compared with Bellini cultivar for Y_2 (production (Mg/ha) and Y_4 (Potato Size > 30mm and < 50mm (%) only during studied seasons. In addition, data showed that, no significant differences between Bellini and Arizona cultivars for Y_1 (leaf area at 90day (cm^2), and Y_7(P in Potato leaves mg/g) during studied seasons and Y_5 (Potato Size > 50mm (%), during season 2019, Y_6 (N in Potato leaves mg/g) during season 2020.

Table (2): Main effect of irrigation systems, cultivars, and fertilization rates on some vegetative growth parameters of potato in both tested seasons

	Seasons / Characteristics / Treatments	2019			2020		
		Y1*	**Y2***	**Y3***	**Y1***	**Y2***	**Y3***
Irrigation systems	**Drip (I_1)**	261.6 a	31.19 a	22.08 b	288.8 a	33.96 a	25.33 b
	Micro-sprinkler (I_2)	243.7 b	28.69 b	25.92 a	269.4 b	29.94 b	27.67 a
L.S.D.at 5%		**4.114**	**0.1139**	**0.3257**	**7.897**	**0.06824**	**0.6117**
Cultivars	**Bellini (C_1)**	254.5 a	28.65 b	26.5 a	282.5 a	31.28 b	29.25 a
	Arizona (C_2)	250.9 a	31.23 a	21.5 b	275.7 a	32.62 a	23.75 b
L.S.D.at 5%		**NS**	**0.1139**	**0.3257**	**NS**	**0.06824**	**0.6117**
Fertilization	**100% MF**	343.1 a	32.71 b	12.5 d	377.7 a	34.65 c	12 e
	75% MF	193.4 d	27.3 d	16.5 c	214 d	28.97 e	20.75 c
	50% MF	145.2 e	22.25 e	52.25 a	160.4 e	23.29 f	54.5 a
	100% MF+BF	340.4 a	35.97 a	9.75 e	374.8 a	37.84 a	9.5 f
	75% MF+BF	275.9 b	32.85 b	7.5 f	306.2 b	35.62 b	13 d
	50% MF+BF	218 c	28.55 c	45.5 b	241.5 c	31.32 d	49.25 b
L.S.D.at5%		**4.361**	**0.3671**	**0.9498**	**4.591**	**0.0738**	**0.8321**

***Y_1 (leaf area at 90day (cm^2), Y_2 (production (Mg/ha), and Y_3 (Size < 30mm (%)**

Table (3): Main effect of irrigation systems, cultivars, and fertilization rates on some vegetative growth parameters of potato in both tested seasons

	Seasons / Characteristics / Treatments	2019				2020			
		Y4*	Y5*	Y6*	Y7*	Y4*	Y5*	Y6*	Y7*
Irrigation systems	Drip (I_1)	53.17 a	24.83 a	51.58 a	4.05 a	48.58 a	26.08 a	51.77 a	4.167 a
	Micro-sprinkler (I_2)	49.67 b	24.58 a	50.26 b	3.917 b	47 b	25.83 b	50.5 b	4.036 b
L.S.D.at 5%		**0.2963**	**NS**	**0.03648**	**0.07295**	**0.8888**	**NS**	**0.356**	**0.08156**
Cultivars	Bellini (C_1)	48.75 b	24.83 a	50.98 a	4 a	44.33 b	26.42 a	51.2 a	4.069 a
	Arizona (C_2)	54.08 a	24.58 a	50.85 b	3.97 a	51.25 a	25 b	51.07 a	4.133 a
L.S.D.at 5%		**0.2963**	**NS**	**0.03648**	**NS**	**0.8888**	**0.4246**	**NS**	**NS**
Fertilization	100% MF	64.11 a	29.25 b	49.4 d	3.65 e	58.75 a	29.25 c	49.63 d	3.875 d
	75% MF	50.75 d	33 a	47.2 e	3.75 d	46.25 c	33 a	47.42 e	3.825 de
	50% MF	33.5 f	14.25 e	46.28 f	3.775 d	31.25 e	14.25 e	46.58 f	3.758 e
	100% MF+BF	65 a	28 c	55.95 a	4.4 a	59.25 a	31.25 b	56.13 a	4.6 a
	75% MF+BF	62.25 b	27.5 c	53.85 b	4.275 b	57.5 b	29.5 c	54.05 b	4.4 b
	50% MF+BF	38.25 e	16.25 d	52.83 c	4.05 c	33.75 d	17 d	53 c	4.15 c
L.S.D.at5%		**1.033**	**0.8008**	**0.08654**	**0.07828**	**0.7571**	**0.8422**	**0.2406**	**0.08251**

***Y4 (Size > 30mm and < 50mm (%), Y5 (Size > 50mm (%), Y6(N in Potato leaves mg/g), Y_7(P in Potato leaves mg/g)**

Effect of fertilization:

Vegetative growth characteristics:

Tables 2 and 3 show the impact of mineral fertilizer (MF) rates (100, 75, and 50% of MF) only and Bio-fertilizers (BF) (Azoasperilum+Bacilus Megatinum) plus (100, 75, and 50% of MF) on vegetative growth parameters of potato plants: Y_1(leaf area at 90 day ,cm^2), Y_2 (production, Mg/ha), Y_4 (Potato Size > 30mm and < 50mm, %), Y_5 (Potato Size > 50mm, %), Y_6(N in Potato leaves, mg/g), and Y_7 (P in Potato leaves, mg/g). Plots served with 100% MF only and 100% MF+BF was significantly higher of Y_1 than another percentage of MF only (75 and 50% of MF) and plus BF during studied seasons. Moreover, plots treated with 100% MF+BF had significantly higher values of Y2 than other percentages of MF only (75 and 50%) and plus BF during studied seasons. Also, plots treated with 50% MF only had significantly higher values of Y_3 than other percentages of MF (100 and 75%) only or plus BF during studied seasons. moreover, Plots treated with 100% MF only and 100% MF+BF had significantly higher values of Y4 than other treatments during studied seasons. In addition, Plots treated with 75% MF only had significantly higher of Y_5 than other treatments during studied seasons. For Y_6 and Y_7 Plots treated with 100% MF+BF only had significantly higher than other treatments. May be phosphate solubilizing bacteria (Bacillus megaterium) improved the availability of P in soil. The obtained results are in agreement with these findings obtained by **Norman et al. (2003); Venkateswarlu et al. (2007); Bin Zakaria (2009) and El-Sayed et al., (2015).**

Interaction between irrigation systems, potato cultivars and fertilization added for vegetative growth characteristics of potato during studied seasons

Data in Tables 4 and 5 present the impact of interactions between irrigation systems, potato cultivars, and fertilization rates on vegetative growth parameters of potatoes. The highest significant values of Y_1 were 362.6, 357, and 355.2 cm^2 for the combination I_1C_1(100%MF+BF), I_1C_2(100%MF), and I_1C_1(100%MF) respectively, while the lowest values were 140 and 139.7 cm^2 for the combination I_2C_1(50%MF) and I_2C_2(50%MF) respectively during season 2019. In 2020, the highest significant values of Y_1 were 398.1, 392.3, and 390.4 cm^2 for the combination I_1C_1(100%MF+BF), I_1C_2(100%MF), and I_1C_1(100%MF) respectively, while the lowest values were 154.9 and 153.1 cm^2 for the combination I_2C_1(50%MF) and I_2C_2(50%MF) respectively. In both growing seasons, Y_1 (leaf area at 90day, cm^2) decreased significantly using a micro-sprinkler irrigation system (I_2) with the mineral fertilization (50%MF), whereas the effect was equal on both cultivars of potatoes.

For Y_2 the highest significant values were 38.81, and 38.25 Mg/ha for the combination I_1C_2(100%MF+BF) and I_2C_2(100%MF+BF) respectively, while the lowest values were 20.27 Mg/ha for the combination I_2C_1(50% MF) during season 2019. In the growing season of 2020, the highest significant value of Y2 was 40.47 Mg/ha for the combination I_1C_2(100%MF+BF), while the lowest value of Y_2 was 22.18 Mg/ha for the combination I_1C_1(50%MF) and I_2C_1(50%MF). It can be noted that Y_2 decreased significantly when using a micro-sprinkler irrigation system (I_2), decreasing the mineral fertilization (50%MF) and Belieny cultivar.

Table (4): Interaction between irrigation systems, fertilization added and cultivars of potatoes during studied seasons

Seasons / Characteristics / Treatments			2019 Y1	2019 Y2	2019 Y3	2020 Y1	2020 Y2	2020 Y3
Drip irrigation	Bellini	100% MF	355.2 a	34.37 c	14 ghi	390.4 a	36.59 e	13 k
		75% MF	200.4 j	28.83 gh	15 gh	223.7 ij	31.05 j	20 h
		50% MF	149.9 l	22.18 m	50 c	168.4 l	22.18 p	55 b
		100% MF+BF	362.6 a	33.26 de	12 i	398.1 a	38.81 b	13 k
		75% MF+BF	293.5 d	31.6 f	15 gh	327.7 d	37.7 d	20 h
		50% MF+BF	232.7 g	27.72 i	42 e	260.1 g	33.26 h	55 b
	Arizona	100% MF	357 a	36.04 b	7 j	392.3 a	38.25 c	7 m
		75% MF	201.3 ij	31.05 f	14 ghi	221 j	32.71 i	18 i
		50% MF	151.1 l	23.28 l	47 d	165.2 l	24.39 o	50 d
		100% MF+BF	341.2 b	38.81 a	4 k	375.6 b	40.47 a	3 o
		75% MF+BF	276.2 e	35.48 b	4 k	303.7 e	38.25 c	5 n
		50% MF+BF	218.2 h	31.6 f	41 e	239.6 h	33.82 g	45 f
Micro-sprinkler irrigation	Bellini	100% MF	329.3 c	29.38 g	16 g	363.2 c	31.05 j	16 j
		75% MF	185.3 k	24.39 k	22 f	206.2 k	25.5 n	25 g
		50% MF	139.7 m	20.27 n	59 a	154.9 m	22.18 p	60 a
		100% MF+BF	328.2 c	33.57 d	15 gh	362 c	35.48 f	12 k
		75% MF+BF	266.4 f	31.6 f	7 j	300.7 ef	33.27 h	15 j
		50% MF+BF	210.5 hi	26.61 j	51 c	234.6 h	28.28 l	47 e
	Arizona	100% MF	331 c	31.05 f	13 hi	365 c	32.71 i	12 k
		75% MF	186.6 k	24.95 k	15 gh	205.1 k	26.61 m	20 h
		50% MF	140 m	23.28 l	53 b	153.1 m	24.4 o	53 c
		100% MF+BF	329.4 c	38.25 a	8 j	363.3 c	36.59 e	10 l
		75% MF+BF	267.5 f	32.71 e	4 k	292.6 f	33.27 h	12 k
		50% MF+BF	210.5 hi	28.27 hi	48 d	231.5 hi	29.94 k	50 d
LSD			**8.722**	**0.7343**	**1.9**	**9.182**	**0.1476**	**1.664**

***Y1 (leaf area at 90day (cm^2), Y2 (production (Mg/ha), and Y3 (Potato Size < 30mm (%)**

Table (5): Interaction between irrigation systems, fertilization added and cultivars of potatoes during studied seasons

		Seasons	2019				2020			
		Characteristics / Treatments	Y4	Y5	Y6	Y7	Y4	Y5	Y6	Y7
Drip irrigation	Bellini	100% MF	54 hi	32 cd	49.8 k	3.7 d	55 f	32 cd	50 h	3.9 fg
		75% MF	51 j	35 a	48.2 o	3.8 d	45 i	35 a	48.5 j	3.8 gh
		50% MF	35 n	15 j	47.1 q	3.8 d	30 m	15 j	47.2 k	3.8 gh
		100% MF+BF	56 h	32 cd	55.8 b	4.5 a	55 f	32 cd	56 b	4.6 ab
		75% MF+BF	60 g	25 h	55.1 d	4.3 b	45 i	35 a	55.4 c	4.3 de
		50% MF+BF	40 m	18 i	52.9 g	4.3 b	30 m	15 j	53 f	4.2 e
	Arizona	100% MF	67 bc	26 gh	49.3 m	3.8 d	67 a	26 g	49.5 hi	4 f
		75% MF	53 ij	33 bc	48 p	3.7 d	49 h	33 bc	48.1 j	3.9 fg
		50% MF	38 m	15 j	46.6 r	3.3 e	35 k	15 j	47 k	3.8 gh
		100% MF+BF	69 ab	27 fg	56.8 a	4.6 a	67 a	30 e	57 a	4.7 a
		75% MF+BF	71 a	25 h	55 d	4.5 a	65 b	30 e	55 c	4.6 ab
		50% MF+BF	44 l	15 j	54.3 e	4.3 b	40 j	15 j	54.5 d	4.4 cd
Micro-sprinkler irrigation	Bellini	100% MF	53 ij	31 de	49.5 l	3.8 d	53 g	31 de	49.8 h	3.8 gh
		75% MF	48 k	30 e	46.6 r	3.8 d	45 i	30 e	46.8 k	3.8 gh
		50% MF	31 o	10 k	45.9 s	3.8 d	30 m	10 k	46.2 l	3.73 gh
		100% MF+BF	60 g	25 h	55.4 c	4.2 bc	55 f	33 bc	55.5 bc	4.5bc
		75% MF+BF	63 ef	30 e	53.2 f	4.2 bc	57 e	28 f	53.5 e	4.4 cd
		50% MF+BF	34 n	15 j	52.3 h	3.8 d	32 l	21 h	52.5 g	4 f
	Arizona	100% MF	61 fg	28 f	49 n	3.8 d	60 d	28 f	49.2 i	3.8 gh
		75% MF	51 j	34 ab	46 s	3.7 d	46 i	34 ab	46.3 l	3.8 gh
		50% MF	30 o	17 i	45.5 t	3.7 d	30 m	17 i	45.9 l	3.7h
		100% MF+BF	64 de	28 f	55.8 b	4.3 b	60 d	30 e	56 b	4.6 ab
		75% MF+BF	66 cd	30 e	52.1 i	4.1 c	63 c	25 g	52.3 g	4.3 de
		50% MF+BF	35 n	17 i	51.8 j	3.8 d	33 l	17 i	52 g	4 f
		LSD	**2.066**	**1.602**	**0.1731**	**0.1566**	**1.514**	**1.684**	**0.4811**	**0.165**

***Y4 (Size > 30mm and < 50mm (%), Y5 (Size > 50mm (%), Y6(N in Potato leaves mg/g), Y7(P in Potato leaves mg/g)**

The current findings are consistent with those obtained by (**Douds et al. 2007; Abou ElKhair and Nawar 2010; Abou-Zeid and Bakry 2011**) who found that the yield of potato significantly when compared to the non-inoculated control. For Y_3 the highest significant percentage 60% for interaction I_2C_1(50%MF) were the same in the studied seasons, while the lowest percentage of Y_3 were (4%, 4%, 4% and 3%) for interaction I_1C_2(100% MF + BF), I_1C_2(75% MF + BF), I_2C_2(75% MF + BF), and I_1C_2(100% MF + BF), during studied season 2019 and 2020 respectively. Moreover, for Y4 the highest significant percentage was (71% and 69%) for interaction I_1C_2(75%MF + BF) and I_1C_2(100%MF + BF), while the lowest percentage of Y_4 were (31% and 30%) for interaction I_2C_1(50% MF), I_2C_2(50% MF) respectively during studied season 2019. In the growing season of 2020, the highest significant percentage of Y_4 were (67%) for interactions I_1C_2(100% MF + BF) and I_1C_2(100% MF), whilst the lowest of Y_4 were the same percentage (30%) for interactions I_1C_1(50% MF + BF) I_1C_1(50% MF), I_2C_1 (50%MF) and I_2C_2 (50%MF). Meanwhile, Y_5 recorded the highest significant percentage (35 and 34%) for interaction I_1C_1(75% MF) and I_2C_2(75% MF), while the lowest percentage 10% was under interaction I_2C_1(75% MF) during season 2019. For the growth season of 2020, the highest significant percentage of Y_5 were (35, 35 and 34%) for interactions I_1C_1(75% MF + BF), I_1C_1(75% MF) and I_2C_2(75% MF) respectively, whilst the lowest percentage of Y_5 was (10%) for interactions I_2C_1(50% MF). On potato, **El Banna et al. (2001); Samey (2006),** and **Amer et al. (2016)** all reported that as water rates increased, the percentage of large tubers increased dramatically.

The data in Tables 4 and 5 show the effect of interactions between irrigation systems, potato cultivars and fertilization rates on the Y_6 parameter. The highest significant values of Y_6 were 56.8 and 57 mg/g for the combination I_1C_2(100% MF+ BF) during both studied seasons of 2019 and 2020 respectively, while the lowest values were 45.5 mg/g and (46.2, 46.3, and 45.9 mg/g) for the interactions I_2C_2 (50% MF) and I_2C_1(50% MF), I_2C_2(75% MF) and I_2C_2(50%MF) during both studied seasons of 2019 and 2020 respectively. In addition, for Y_7 the highest significant values were 4.5, 4.6, and 4.5 mg/g for the interactions I_1C_1(100% MF+ BF), I_1C_2(100% MF+ BF) and I_1C_2(75% MF+ BF) respectively during season 2019, while the lowest value of Y_7 was 3.3mg/g for the interaction I1C2 (50% MF). Moreover, in 2020, the highest significant values of Y_7 were 4.6, 4.7, 4.6 and 4.6 mg/g for the interactions I_1C_1(100% MF+ BF), I_1C_2(100% MF+ BF), I_1C_2(75% MF+ BF) and I_2C_2(100% MF+ BF) respectively, whilst the lowest value of Y_7 was 3.7 mg/g for the interactions I_2C_2(50% MF). These findings could be attributed to the beneficial effects of interaction between mineral fertiliser elements and effective microorganisms on plant growth, as measured by yield, component, and quality metrics of potato. Also, bio-fertilizers such Azotobacter, Azospirillum, and Pseudomonas increased the availability of nitrate, nitrite, and phosphate in the roots and leaves of the Rauwolfia serpentine and promoted plant growth. The obtained results are compatible with the results obtained by (**Hammad and Abdel-Ati 1998; Abou ElKhair and Nawar 2010; Abou-Zeid and Bakry 2011; Rai et al. 2017**).

Water-use efficiency (WUE) and irrigation water-use efficiency (IWUE)

Table (6) shows irrigation water use efficiency (IWUE) values that varied from a minimum of 3.27 kg/m^3 for the I_2C_1(50% MF) treatment to a maximum of 7.61 kg/m^3 for the I_1C_2(100% MF+BF) treatment in the growing season of 2019. In the growing season of 2020, IWUE values ranged from a minimum of 3.58 kg/m^3 for the I_2C_1(50% MF) treatment to a maximum of 7.94 kg/m^3 for the I_1C_2(100% MF+BF) combination. The maximum and minimum values of water use efficiency (WUE) in the growing season of 2019 were 6.51 kg/m^3 and 2.77 kg/m^3 for the I_1C_2(100% MF+BF) and I_2C_1(50% MF) treatments, respectively. The corresponding values were 6.78 kg/m^3 and 3.03 kg/m^3 kg in the same treatments in 2019 respectively, in season 2020. The obtained results showed that the WUE and IWUE values increased with the interaction I_1C_2(100% MF+BF). broadly, several factors affect the WUE, such as irrigation system, nutritive elements, soil salinity, and soil-borne diseases **Kashyap and Panda (2003); Yuan et al. (2003); Onder et al. (2005); Ayas and Korukçu (2010) and Abuarab et al., 2019)** also reported similar findings for the potato crop.

Table (6): WUE and IWUE under interaction between irrigation systems, fertilization added and cultivars of potatoes during

Seasons / Characteristics / Treatments			2019 WUE	2019 IWUE	2020 WUE	2020 IWUE
Drip irrigation	Bellini	100% MF	5.76 c	6.74 c	6.13 e	7.17 e
		75% MF	4.83 f	5.66 f	5.20 i	6.08 i
		50% MF	3.72 l	4.34 l	3.71 q	4.34 r
		100% MF+BF	5.57 d	6.53 d	6.51 b	7.61 b
		75% MF+BF	5.29 e	6.2 e	6.32 d	7.39 d
		50% MF+BF	4.64 g	5.43 g	5.57 g	6.52 g
	Arizona	100% MF	4.01 j	4.74 j	4.24 n	5.01 n
		75% MF	3.33 m	3.93 m	3.48 s	4.11 t
		50% MF	3.90 k	4.56 k	4.08 o	5.72 k
		100% MF+BF	6.51 a	7.61 a	6.78 a	7.94 a
		75% MF+BF	4.32 i	5.09 i	4.54 l	5.36 l
		50% MF+BF	3.63 l	4.29 l	3.86 p	4.56 q
Micro-sprinkler irrigation	Bellini	100% MF	6.04 b	7.07b	6.41 c	7.50 c
		75% MF	5.2 e	6.09 e	5.48 h	6.41 h
		50% MF	2.77 o	3.27 o	3.03 u	3.58 V
		100% MF+BF	5.59 g	5.42 g	6.41 c	7.50 c
		75% MF+BF	5.94 b	6.96b	5.66 f	6.63 f
		50% MF+BF	5.29 e	6.2 e	4.85 k	4.78 p
	Arizona	100% MF	4.24 i	5.01 i	4.47 m	5.27 m
		75% MF	3.41 m	4.02 m	3.63 r	4.29 s
		50% MF	3.18 n	3.75 n	3.33 t	3.93 u
		100% MF+BF	5.23 e	6.17 e	5.01 j	5.90 j
		75% MF+BF	4.47 h	5.27 h	4.54 l	5.36 l
		50% MF+BF	3.86 k	4.56 k	4.09 o	4.83 o
LSD			**0.28**	**0.033**	**0.008**	**0.009**

Correlation coefficient among the measured parameters of potato cultivars

It is clear from Table (7) that the correlation coefficient between the measured parameters of potato varieties is high as seen in the table. The following are the most important results: There was a strong positive relationship between leaf area at 90day (cm^2) and (Production (Mg/ha), IWUE (Kg/m^3), WUE (Kg/m^3), (N in Potato leaves mg/g), Potato Size > 30mm and < 50mm (%), Potato Size > 50mm (%) and (P in Potato leaves mg/g) and the investigated factors. on the contrary, there was an inverse relationship between the Leaf area at 90day (cm^2) and (Potato Size < 30mm (%). The interpretation of the above was that the potato cultivars were strong and healthy and received the appropriate amount of irrigation water and appropriate fertilization as well. The same preceding statement applies to both productions, IWUE and WUE with other parameters. For N content in Potato leaves, mg/g, there was an inverse relationship between N in Potato leaves mg/g and (Potato Size < 30mm (%), and there was no significant correlation coefficient with potato Size > 50mm (%). For P in Potato leaves mg/g, the same correlation was found as N in Potato leaves mg/g, there was no significant correlation.

For Potato Size < 30mm (%), it was found that there was a negative relationship with all parameters of potato cultivars except there was no correlation coefficient with potato Size > 50mm (%).

For Potato Size > 30mm and < 50mm (%), it was found that there was a positive relationship with Leaf area at 90day (cm^2), (Production (Mg/ha), IWUE (Kg/m^3), WUE (Kg/m^3), N in Potato leaves mg/g, (P in Potato leaves mg/g) and Potato Size > 50mm (%). Moreover, (%), it was found that there was a negative relationship with Potato Size < 30mm (%) only.

For Potato Size > 50mm (%), it was found that there was a positive relationship with Leaf area at 90day (cm^2), (Production (Mg/ha), IWUE (Kg/m^3), WUE (Kg/m^3), and Potato Size > 30mm and < 50mm (%). Also, there was no correlation coefficient with **N in** Potato leaves mg/g, (P in Potato leaves mg/g) and Potato Size < 30mm (%). These findings corroborated those of **Yuan et al. (2003),** who found that increasing irrigation water enhanced plant height, biomass, and tubers at irrigation regimes of (125,100,75,50, and 25) evaporated water.

Table (7): Correlation coefficient among the measured parameters of potato cultivars

Treatments	Leaf area at 90day (cm^2)	(Production (Mg/ha),	IWUE (Kg/m^3)	WUE (Kg/m^3)	N in Potato leaves mg/g)	P in Potato leaves mg/g)	Potato Size < 30mm (%)	Potato Size > 30mm and < 50mm (%)	Potato Size > 50mm (%)
Leaf area at 90day (cm^2)	1								
(Production (Mg/ha),	0.869**	1							
IWUE (Kg/m^3)	0.722**	0.908**	1						
WUE (Kg/m^3)	0.715**	0.902**	1.000**	1					
(N in Potato leaves mg/g)	0.644**	0.774**	0.667**	0.663**	1				
(P in Potato leaves mg/g)	0.480**	0.642**	0.577**	0.574**	0.879**	1			
(Potato Size < 30mm (%)	-0.738**	-0.736**	-0.603**	-0.596**	-0.419*	-0.0364	1		
(Potato Size > 30mm and < 50mm (%),	0.746**	0.755**	0.623**	0.616**	0.493*	0.428*	-0.954**	1	
Potato Size > 50mm (%),	0.563**	0.541**	0.434*	0.429*	0.196	0.168	-0.0862	0.671**	1

**** Correlation is significant at the 0.01 level (2-tailed).**

*** Correlation is significant at the 0.05 level (2-tailed).**

4. CONCLUSIONS

The overall aim of this research study was to evaluate the effects of irrigation systems (drip and micro-sprinkler) and different rates of mineral and bio-fertilizer on the yield and water use efficiency of potatoes. The results showed that drip irrigation had a remarkable significant impact on the production and vegetative growth parameters of potatoes. In 2019 and 2020, the I_1C_2(100%MF+BF) treatment produced the maximum yields of 38.81 Mg ha^{-1} and 40.47 Mg ha^{-1}, respectively. The IWUE and WUE values declined as the micro-sprinkler irrigation system was used and MF percentage was reduced, according to the findings. In addition, the (micro-sprinkler irrigation system + 50 MF+ potato cultivars) produced less yield as well as fewer less yield components. Under the conditions of Wadi El Natrun, Beheira Governorate, a drip irrigation system with (mineral fertilization + bio fertilization) + potato cultivars are recommended for potato production.

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تقييم تأثير أنظمة الري ومعدلات مختلفة من التسميد المعدني والحيوي على محصول البطاطس وكفاءة استخدام المياه

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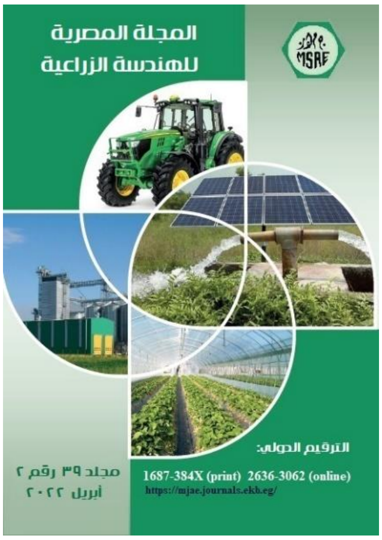
[٢] أستاذ ميكروبيولوجي الأراضي - معهد الدراسات والبحوث البيئية - جامعة مدينة السادات - المنوفية - مصر.

[٣] طالب دراسات عليا بمعهد الدراسات والبحوث البيئية - جامعة مدينة السادات - المنوفية - مصر.



الكلمات المفتاحية:
نظام الري؛ البطاطس؛ التسميد المعدني؛ التسميد الحيوي؛ إنتاجية المياه.

الملخص العربي

أجريت تجربتان حقليتان خلال موسمي الصيف ٢٠١٩ و٢٠٢٠ في مزرعة خاصة بمنطقة وادى النطرون، محافظة البحيرة، وذلك لدراسة تقييم تأثير نظامين للري (الري بالتنقيط والري بالرش) ومعدلات مختلفة من التسميد المعدني منفردا (١٠٠٪، ٧٥٪، ٥٠٪ من التوصية السمادية للبطاطس) ونفس النسب السابقة من التسميد المعدني مضاف إليها التسميد الحيوي (*Azoasperilum* كمثبت نتروجين + *Bacillus megaterium* كمذيب للفوسفور) على محصول البطاطس (بلينى – أريزونا) وكفاءة استخدام المياه. وتم تصميم التجربتان بنظام القطاعات المنشقة مرة واحدة في ثلاث مكررات حيث كانت المعاملة الرئيسية نظامي الري (الري بالتنقيط – الري بالرش) بينما المعاملات الشقية صنفي البطاطس (بلينى – أريزونا) ونسب التسميد المعدني منفردا وكذلك مختلطا بالتسميد الحيوي. وكانت النتائج المتحصل عليها:

- وجود فروق معنوية للري بالتنقيط مقارنة بالري بالرش لصفات النمو (مساحة سطح الورقة، الإنتاجية، تدريج البطاطس Y_4)، وكذلك محتوى الأوراق من النيتروجين والفوسفور. في حين تفوق الري بالرش على الري بالتنقيط في تدريج البطاطس (Y_3) فقط بينما لم تسجل فروق معنوية بين النظامين في صفة تدريج البطاطس (Y_5).
- وجود فروق معنوية لصفات النمو وصفات المحصول للمعاملة (الري بالتنقيط و١٠٠٪ تسميد معدني أو مختلط بالتسميد الحيوي مع صنفي البطاطس) لكل من مساحة سطح الورقة – الإنتاجية – التدريج (Y_4)، وكذلك محتوى الأوراق من النيتروجين والفوسفور خلال موسمي الزراعة ٢٠١٩-٢٠٢٠.
- وجود فروق معنوية للمعاملة (الري بالرش + صنف بلينى + ٥٠٪ تسميد معدني) في صفة التدريج (Y_3) فقط.

يوصى بتطبيق نظام الري بالتنقيط مع أي من صنفي البطاطس و١٠٠٪ من التسميد المعدني المقترن بالتسميد الحيوي لما وفره نظام الري بالتنقيط في كمية المياه وزيادة معنوية في معظم صفات النمو للبطاطس مقارنة بنظام الري بالرش.