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Enhancing the productivity of potato crop under drought stress by using some biological treatments

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ABSTRACT

The objectives of current investigation were to investigate the effect of various microbial treatments on the growth and productivity of potato, and nutrient uptake under different irrigation regimes and to study the influence of bacteria to alleviate the negative impact of water deficit irrigation. Therefore, the present study was conducted as a factorial experiment, which the main plot was assigned to various irrigation regimes (100% of crop evapotranspiration ETc, 80% ETc and 60% ETc) and sub-plots were assigned to microbial treatments (control = ck, *Azotobacter chroococcum* + *Azospirillum brasilense* =AZ, *Bacillus megaterium* = BM, *Bacillus circulans* = BC and combined AZ+BM+BC = Mix). The main results revealed that the actual amount of water applied was varied according to irrigation regime level and potato growth stage. Increase of water deficit irrigation resulted in a significant decrease in plant height, yield and yield components, dry tubers yield, starch and protein yield, and nitrogen, phosphorus and potassium uptake, however, increased irrigation water use efficiency and economic productivity of irrigation water. Microbial inoculation enhanced all the above studied parameters under various irrigation regimes compared to non-inoculated treatment (control). For the interaction effect, with 20% water-saving a irrigation regime 80% ETc, combined microbial treatment the average reduction in both season for tuber weight per plant, marketable yield and tubers total yield were 7.56%, 7.75% and 7.56% compared to 100% ETc, respectively. However, compared to control at 100% ETc, Mix treatment increased the total yield in both seasons by 19.26%. Moreover, protein and starch yield, dry tubers yield and nitrogen, phosphorus and potassium uptake were higher when potato plants irrigated with 100% ETc and inoculated with combined microbial treatment.

Keywords: Calcareous soil, irrigation regime, microbial treatment, nutrient uptake, tubers yield

Introduction

The world population is growing and predicted to reach 8.6 billion in 2030 according to the United Nations report (21 June 2017). Consequently, great pressure is placed on farmable land, water, energy and biological resources to provide an adequate supply of food while preserving the integrity of ecosystem. It was well-documented that the loss of arable land due to either salinization or drought has posed a major challenge for maintaining world food supplies for the growing population. In many regions all over the world drought poses one of the most important constraints to plant growth and productivity (Chaves *et al.,* 2003). Moreover, availability of water is becoming even scarcer for agricultural communities. Also, Nadeem *et al.* (2014) and Delshadi *et al.* (2017) reported that drought stress has direct effects on the nitrogen fixation amount in plants. In addition, drought stress bothers mineral nutrient linkups, hindering plant growth and evolvement, which reflects on the ultimate crop yield. Drought usually decreases mass flow consequently mineral nutrient uptake and the transmission of these nutrients from the roots to the shoot, influencing in all metabolic activity of plant physiology (Silva *et al.* 2011; Bista *et al.,* 2018). Therefore, for the next decade, one of the great challenges is to mitigate any effect of climate change on crop production with a main focus being to maintain crop

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production levels with reduced availability of water (Obidiegwu *et al.,* 2015). Consequently, it is very important to find an approach to increase the crop tolerance to drought stress.

On the other side, calcareous soils constitute more than 30% of the world's land surface area, and their $CaCO_3$ content wobbled from a few percent to 95% (Marschner, 1995). Calcareous soils formed naturally in arid and semiarid regions because of relativity scarce leaching. They also occur in humid and semi humid zones if their parent material is affluent in $CaCO_3$, such as limestone and shells (Brody and Weil, 1999). El-Damaty *et al.* (1973) suggested 8-10% $CaCO_3$ as limit for defining calcareous soils. In Egypt, the calcareous soils comprise about 25-30% of the total area (Taalap *et al.,* 2019). The most fastidious problems for lucrative using of calcareous soils in agriculture are their poor physico-chemical characteristics and comrade poor water retention, and speedily fixation of applied nutrients if added to the soil. Generally, calcareous soils tend to be low in available nitrogen and total organic matter (Wahba *et al.,* 2019). The high pH level (may exceed 9) performs in unavailability of phosphorus, iron, manganese, zinc and copper (Imas and Sheva, 2000). As well as problems of potassium and magnesium nutrition because imbalance between these elements and calcium (Yuncong, 2001). Consequently, chlorosis symptoms are usually observed on plants grown in calcareous soils. But potential productivity may be very high where adequate water and nutrients can be provided (Wahba *et al.,* 2019).

Previous studies reported that application of high nitrogen doses could alleviate the negative effects of water deficit and improve plant growth (Halvorson and Reule 1994; Fife and Nambiar 1997; Van-Schaik *et al.* 1997; Saneoka *et al.* 2004). However, the use of chemical fertilizers cause the damage to our ecosystem, atmosphere and harmful to human health (Goyal *et al.* 2005, Ju *et al.* 2018); plus it is the greatest input cost for a large number of crops (Amiour *et al.* 2012). Recently, due to technological advances in next generation sequencing and microbiomics, attention has turned to the application of beneficial microorganisms as biofertilizer, that mediate drought tolerance, improve plant water use efficiency (Jochum *et al.* 2019) and improve soil properties (Nadeem *et al.* 2014).

Biofertilizers are products including living cells of distinct types of microbial which when applied to seed, soil or plant surface colonize the rhizosphere or the plant interior. Consequently, enhancement growth by transferring nutritionally serious elements (macro and micro nutrients) from unusable to usable form through different biological process such as nitrogen fixation, solubilization of insoluble phosphate and silicate minerals or potassium releasing (Rokhzadi *et al.,* 2008; Farag Jr *et al.,* 2013; Mamnabi *et al.,* 2020). In addition, microorganisms in biofertilizers support decomposition of organic matter, increasing availability of nutrients, production of antibiotics, phytohormones i.e. IAA, GAs and cytokinin, protect plants from pests and diseases and enhancement crop production (Bhattacharyya and Jha, 2012; Khosro and Yousef, 2012). In this respect, Delshadi *et al.* (2017) reported that some bacterial species as biofertilizers are widely used to increase plant growth, yield, seed production and biological control in various crops. This could increase nutrient uptake and improves drought tolerance (Suhag (2016) and help the plants to overcome the negative effects of water deficit (Azab 2016).

Potato (*Solanum tuberosum* L.) is the most important non-cereal food crop worldwide and ranks as the fourth most important food crop and is of great economic value (Pino *et al.,* 2007, Obidiegwu *et al.,* 2015). It is often considered as a drought sensitive crop and its production is threatened due to frequent drought episodes (Obidiegwu *et al.,* 2015). Moreover, potato yield in reclaimed lands are highly profitable and greater than crop yield obtained in the Nile Delta and Nile Valley (Mosa, 2012). Taking into consideration that the experiment soil is calcareous soils, which are widely occurrence in the desert areas of Egypt, it cause some physico-chemical problems that affect crop production, water use efficiency and availability of nutrients in this kind of soil (Abou-Hussien *et al.,* 2019). Consequently, application of *Azotobacter chroococcum, Azospirillium brasilense, Bacillus megaterium* and *Bacillus circulans* could be an appropriate method to improve potato yield, yield components and yield quality under water deficit conditions in calcareous soils. However, to the best of our knowledge, the concepts of microbial inoculation and various irrigation regimes have not been fully integrated for potato crop in previous studies.

The structure and chemical composition of potato fraction, such as proteins, starch, organic and inorganic compounds, non-starch polysaccharides, sugars, macro and micro nutrients (P, K, Mg, Ca, Fe, Mn, Zn and Cu) influence the quality of potatoes especially for industrial and food purposes products (Ekin, 2011; Dupuis and Qiang 2019). Only after harvest, potato tubers contain about 80% of water and 20% of dry matter. Almost 60 to 80% of the dry matter is starch (Ekin, 2011). Starch is a natural polymer appearing in all plant organisms, an indirect output of photosynthesis, and it has called a biodegradable substance (Leszczyński 2004). For potato chips production tubers should contain 14-17% of starch and 20-22% of dry matter, while 12-16% of starch and 18-22% of dry matter for suitable immediate consumption (Lisińska 2000; Zgórska and Frydecka-Mazurczyk 2002; Baranowska, 2018).

Therefore, the current study aimed to investigate the effect of various microbial treatments on the growth and productivity of potato, and nutrient uptake under different irrigation regimes and to study the influence of bacteria to alleviate the negative impact of water deficit irrigation.

Materials and Methods

1. Plant material and experimental site

The field trials of potato crop (*Solanum tuberosum* L.*,* cv. Cara) were conducted during two growing seasons, 2017/2018 and 2018/2019 at the Research Farm of Arab El- Awammer Research Station, ARC, Asyut, Egypt (Latitude 27°, 03′ N and Longitude 31°, 01′ E and the Altitude 71 m above sea level). Detailed monthly meteorological data in Asyut during the growth seasons are reported in Table (1)**.** The experiments were conducted in sandy calcareous soil and the classification of soil was Typic Torripsamments agreement with Soil Taxonomy (Soil Survey Staff 2010). Representative soil samples from the field experimental surface layer (0-25 cm) were collected before cultivation and air-dried then crushed, and sifted to pass through 2 mm. The physical and chemical properties were determined by the standard methods reported by Klute (1986) and Jackson (1973), and the obtained results are presented in Table 2.

Table 1: Average monthly meteorological data of Asyut weather station during the two growth seasons of 2017/2018 and 2018/2019.

	Temperature (°C)		Relative humidity (%)	Wind speed (km/h)	Sunshine hours (h)	ETo (mm)
	Max	Min				
			2017/2018			
November	25.1	10.9	54.6	15.2	9.4	4.75
December	23.2	9.0	58.8	14.6	9.0	3.98
January.	19.9	6.5	57.5	15.3	8.9	3.73
February.	26.1	11.2	44.3	14.4	9.7	5.63
			2018/2019			
November	26.5	13.1	53.8	14.7	9.4	4.93
December	20.8	8.0	62.8	16.3	9.0	3.62
January.	19.3	5.8	52.8	13.9	8.9	3.70
February.	21.8	7.6	51.4	17.3	9.7	4.93

Table 2: Physical and chemical properties of representative composite soil sample from surface layer (0-25 cm) of the field experimental site.

Chemical properties

pH (1 : 1)	EC dS/ m (1 : 1)	Soluble cations (meq / L)				Soluble anions (meq / L)		Available phosphorus (ppm)	Total nitrogen (%)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--} + HCO_3^{-}	Cl^{-}		
8.44	0.41	1.59	1.25	0.38	0.78	1.89	1.64	7.01	0.01

Physical properties

Particle size distribution (%)			Texture class	Moisture content (Volumetric %)			O.M (%)	$CaCO_3$ (%)	Bulk density
Sand	Silt	Clay		S. P.	F.C.	W.P.			
91.1	5.7	3.2	Sandy	23.0	10.9	4.5	0.40	29.80	1.60

2. Experimental design

The present investigation was carried out as a randomized complete block design in a split-plot with three replications. The first factor was assigned in main plot to irrigation regimes 100% ETc, 80% ETc and 60% of crop evapotranspiration ETc). The second factor was assigned in sub plot to microbial treatments (control=ck, *Azotobacter chroococcum* + *Azospirillum brasilense* =AZ, *Bacillus megaterium*

=BM, *Bacillus circulans* =BC and combined AZ+BM+BC=Mix), which provided from Central Lab. of Organic Agriculture, Agricultural Research Centre, Giza, Egypt. The field experiment was conducted under drip irrigation system and the plot area was 20 m^2.

3. Plant growth conditions

Healthy potato tubers were sown on one side of each dripper line at 30 cm in between during second week of October in both seasons. During the soil preparation phosphorus was added at the rate of 107.1 kg P_2O_5/ha in the form of granular superphosphate (15% P_2O_5). Nitrogen fertilizer was added in the form of ammonium nitrate (33.5% N) at the rate of 214.3 kg N/ha in six equal doses via the irrigation system. However, potassium was applied at the rate of 119 kg K_2O/ha through irrigation system in six equal doses in the form of potassium sulfate (50% K_2O). Cheated Fe, Mn and Zn in liquid solution, containing 100 ppm of each was used as foliar spray, sprayed twice. The other agriculture practices were carried out according to the potato extension guide - Ministry of Agriculture, Egypt. At the first week of February irrigation was stopped then potato plants were harvested on March third and second in the first and second seasons, respectively. CROPWAT model was used to calculate reference evapotranspiration with Penman Monteith (Smith, 1991).

Crop evapotranspiration (ETc): (Allen *et al.* 1998)

$$ET_c = ET_0 \times Kc$$

Where:-

ETc = Crop evapotranspiration.
ET_0 = Reference evapotranspiration.
Kc = Crop coefficient (from FAO 56)

The crop coefficient (Kc) for potato growth stages (initial, developmental, middle and tuber maturity stages) was 0.50, 0.65, 1.15 and 0.75, respectively.

Irrigation water applied:-

The amounts of actual irrigation water applied under each irrigation treatment were determined using the following equation**:** James (1988)

$$I.Ra = \frac{ETc + LF}{Er}$$

Where:
I.Ra = total actual irrigation water applied mm/ interval.
ETc = Crop evapotranspiration using Penman Monteith equation.
Lf = leaching factor (10 %).
Er = irrigation system efficiency (85%).

4. Yield and yield components

After 10 weeks from cultivation, five plants from each plot were used to measure plant height (cm). After harvesting, tubers fresh weight/plant (g), marketable tubers weight /plant (g), total tuber yield (ton/ha) and marketable tubers yield (ton/ha) were measured. Dry tubers yield (ton/ha) was determined as follow:

$$Dry\ tubers\ yield\ (ton/ha) = \frac{Potato\ total\ tubers\ yield\ (ton/ha)\ x\ Dry\ matter\ (\%)}{100}$$

Where, dry matter percentage was determined according to Haque *et al.* (2018).

$$Dry\ matter\ (\%) = \frac{Dry\ weight\ (g)}{Fresh\ weight\ (g)} x100$$

5. Irrigation water use efficiency (IWUE, kg/m^3):-

The irrigation water use efficiency (IWUE) values were calculated as follows kg/m^3:

$$IWUE\ (kg/m3) = \frac{Tubers\ potato\ yield\ (kg/ha)}{Irrigation\ Water\ Applied\ (m3/ha)}$$

6. Economic productivity of irrigation water (EPIW, \$/m^3):

EPIW was calculated according to Molden (1997) as follow \$/m^3:

$$EPIW\ (\$/m3) = \frac{Gross\ value\ of\ product\ (\$/ha)}{Total\ amount\ of\ irrigation\ applied\ water\ (m3/ha)}$$

7. Biochemical measurements

Five whole potato tubers from each plot were randomly selected and then the fresh weight was recorded. Healthy tubers were washed with running tap water and followed with distilled water. After washing, clean tubers were cut into 2-3 mm slices. Tubers slices were oven-dried at 70 °C until a constant weight was achieved then the dry weight was determined. Dried tubers were ground to fine powder and accurately 0.5g weighted for wet digestion using a mixture of sulfuric acid and hydrogen peroxide (Parkinson and Allen 1975). The digested samples were used to measure nitrogen (N), phosphorus (P) and potassium (K). N determination was carried out using micro-kjeldahl procedure (Jackson 1973). Total phosphorus was determined coloremetrically by the stannous chloride phosphomolybdic-sulfuric acid method as described by Jackson (1973) and total potassium was measured by the flame photometric method (Page, 1982). Protein and starch yield (kg/ha), and N, P and K uptakes (kg/ha) were determined as follows:

$$Protein\ yield\ (kg/ha) = tubers\ dry\ yield\ (ton/ha)\ \times protein\ (\%) \times 10$$

Where, protein percentage was determined according to Ranganna (1977) as follow:

$$Protein\ (\%) = Nitrogen\ \%\ \times 6.25$$

$$Starch\ yield\ (kg/ha) = tuber\ dry\ yield\ (ton/ha) \times starch\ (\%)\ \times 10$$

Where, starch (%) was calculated according to Burton (1948) method as follow:

$$Starch\ (\%) = 17.457 + \{0.891 \times (dry\ mater\ \% - 24.182)\}$$

$$Nitrogen\ uptake\ (kg/ha) = tubers\ dry\ yield\ (ton/ha) \times N\ \%\ \times 10$$

$$Phosphorus\ uptake\ (kg/ha) = tubers\ dry\ yield\ (ton/ha) \times P\ \%\ \times 10$$

$$potassium\ uptake\ (kg/ha) = tubers\ dry\ yield\ (ton/ha) \times K\ \%\ \times 10$$

8. Data analysis

All obtained data were subjected to statistical analysis of variance and treatment means were compared for significant differences using the Duncan's multiple range test at $p = 0.05$. The MSTAT-C 2.10 computer program was used to perform all the analysis of variance in accordance with the procedure obtained by Steel and Torrie (1982). Data are presented as the means ± standard deviations.

Results

1. Crop evapotranspiration (ETc, mm)

Results in Fig. 1 indicated that crop evapotranspiration was increased in accordance with plant growth development, which recorded the maximum value (155.7 mm and 144.1 mm in the 1st and 2nd seasons, respectively) at the third development stage (Mid-season stage). Then it was decreased at the fourth development stage, which were 76.1 mm and 76.0 mm during 2017/2018 and 2018/2019 seasons, respectively.

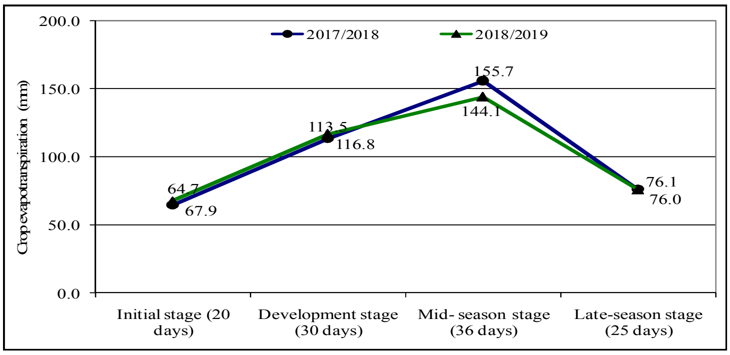

Fig. 1: Changes of crop evapotranspiration (mm) during various development stages of potato crop during 2017/2018 and 2018/2019 seasons.

2. Irrigation water applied (m^3/ha)

To know the actual amount of water applied under various irrigation regime during seasons of 2017/2018 and 2018/2019, the irrigation water applied was calculated (m^3/ha) at four development stages of potato crop. Data presented in Fig. 2 revealed that the total amount of applied water for potato grown under different irrigation regimes were 5306.0, 4244.8 and 3183.6 m^3/ha in the first season for 100%, 80 and 60% ETc, respectively, and were 5208.3, 4166.6 and 3125.0 m^3/ha in the second season. The data in Fig. 2 showed that, the irrigation water applied varies from growth stage to another through the two growth seasons. The lowest value was at the beginning of the growth season. As the plant developed, a gradual increase is observed in water consumption. The irrigation water applied reached its peak at the mid-season stage. After that, the rate of irrigation water applied pronouncedly decreased during the late season of plant growth. The obtained results indicated that the seasonal irrigation water applied was mostly influenced by irrigation treatments.

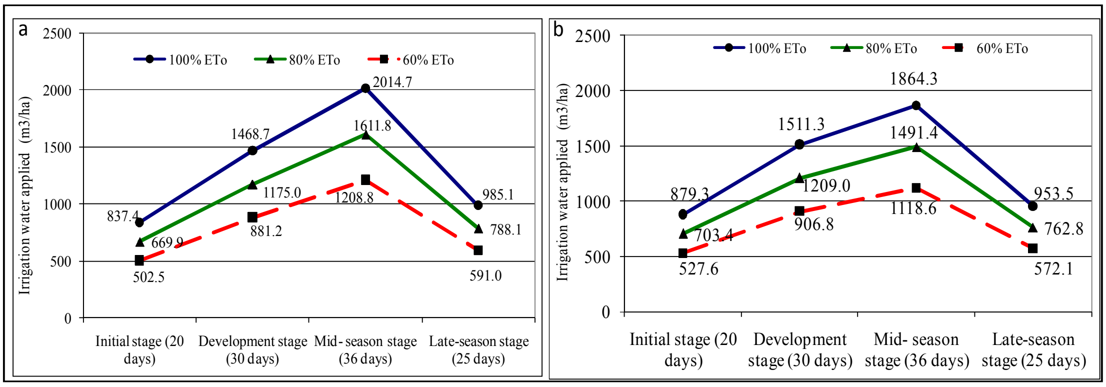

Fig. 2: Irrigation water applied (m^3/ha) at different growth stages of potato grown under different irrigation regimes during the seasons of (a) 2017/2018 and (b) 2018/2019

3. Plant height (cm)

The height of potato plants in response to various irrigation regimes and biological treatments was measured. As shown in Table 2, irrigation regimes, biological treatments and their interaction significantly affected the plant height of potato ($p<0.01$). With decreasing irrigation regimes from 100%ETc to 60%ETc, the plant height was significantly decreased during both seasons (from 34.35cm and 36.49cm for 100%ETc to 30.53cm and 32.19cm for 60%ETc in 2017/2018 and 2018/2019 seasons, respectively. Regarding to inoculation treatments, Mix treatment (AZ+BM+BC) recorded the longest height of plants (34.83cm and 38.01cm), which was not significantly differ from AZ treatment (Table 3). Results of the interaction effect revealed that plants treated with combined microbial (Mix) under irrigation regime 100% ETc showed highest value of plant height (36.58cm and 40.52cm). This was not significantly varied from the same inoculation treatment (Mix) under irrigation regime 80%ETc in two seasons.

4. Tubers weight per plant (g)

To compare the influence of water shortage, inoculation with various bacteria, and their interaction on potato yield, the tubers weight/plant (plant yield) was measured (Table 3). The mean of plant yield (g) was decreased 20.47% and 20.64% under irrigation regime 60%ETc compared to 100%ETc during two seasons, respectively. Moreover, biological treatments increased significantly the tubers weight per plant compared to un-inoculated plants (control, CK) in both seasons. The highest increase was observed with Mix treatment, which was 30.26 % and 40.31% compared to control during 1st and 2nd seasons, respectively. Mix treatment under irrigation regime 100%ETc gave the biggest mean of plant yield (835.64 g and 926.54 g in first and second seasons, respectively), which not differ from BC treatment under 100%ETc. With saving 20% of irrigation water, weight of tuber/plant was decreased 7.59% and 7.53% under 80%ETc and treated plants with AZ+BM+BC (Mix treatment) compared to 100%ETc with the same microbial treatment.

Table 3: Plant height (cm), tubers weight/plant (g), weight of marketable tubers/plant (g) and marketable tubers yield (ton/ha) as influenced by various irrigation regimes and different microbial treatments as well as their interaction.

Treat.	2017/2018			
	100% ETc	80% ETc	60% ETc	Mean
		Plant height (cm)		
CK	32.58±0.80^{de}	31.12±0.38^{fg}	28.00±0.66^{h}	30.57^{c}
AZ	35.42±0.58^{b}	36.00±0.25^{ab}	31.82±0.35^{ef}	34.41^{a}
BM	33.92±0.76^{c}	33.33±0.63^{cd}	30.58±0.14^{g}	32.61^{b}
BC	33.25±0.50^{cd}	33.00±0.25^{d}	30.42±0.14^{g}	32.22^{b}
Mix	36.58±0.38^{a}	36.08±0.52^{ab}	31.83±0.29^{ef}	34.83^{a}
Mean	34.35^{a}	33.91^{a}	30.53^{b}	
		Tubers weight/plant (g)		
CK	670.29±32.50^{def}	611.42±21.40^{fg}	453.36±14.76^{h}	578.35^{d}
AZ	676.15±24.70^{def}	683.32±34.02^{de}	623.78±38.46^{efg}	661.08^{c}
BM	715.26±25.71^{cd}	664.74±33.10^{def}	619.70±28.49^{efg}	666.57^{c}
BC	792.98±35.77^{ab}	754.30±37.22^{bc}	588.31±40.66^{g}	711.86^{b}
Mix	835.64±67.75^{a}	772.18±31.99^{abc}	652.30±29.81^{defg}	753.37^{a}
Mean	738.07^{a}	697.19^{b}	587.49^{c}	
		Weight of marketable tubers/plant (g)		
CK	511.94±26.23^{ef}	455.33±46.97^{g}	305.92±10.53^{h}	424.39^{d}
AZ	635.18±32.00^{bc}	553.55±30.77^{de}	490.93±37.94^{fg}	559.89^{c}
BM	592.63±19.79cd	599.78±24.13^{cd}	527.05±45.32^{ef}	573.15^{c}
BC	682.75±10.55^{ab}	609.73±42.35^{cd}	529.86±24.45^{ef}	607.45^{b}
Mix	707.62±27.05^{a}	652.53±29.56^{abc}	610.09±40.84^{cd}	656.75^{a}
Mean	626.02^{a}	574.18^{b}	492.77^{c}	
		Marketable tubers yield (ton/ha)		
CK	20.469±1.05^{ef}	18.206±1.88^{g}	12.232±0.42^{h}	16.969^{d}
AZ	25.397±1.28^{bc}	22.133±1.23^{de}	19.629±1.52^{fg}	22.387^{c}
BM	23.696±0.79^{cd}	23.982±0.96^{cd}	21.074±1.81^{ef}	22.917^{c}
BC	27.299±0.42^{ab}	24.380±1.69^{cd}	21.186±0.98^{ef}	24.288^{b}
Mix	28.294±1.08^{a}	26.091±1.18^{abc}	24.394±1.63^{cd}	26.259^{a}
Mean	25.031^{a}	22.958^{b}	19.703^{c}	
		2018/2019		
		Plant height (cm)		
CK	34.18±0.94^{b}	33.56±0.70^{b}	29.80±0.32^{d}	32.51^{c}
AZ	39.20±0.29^{a}	39.19±0.88^{a}	34.00±1.37^{b}	37.46^{a}
BM	34.98±0.44^{b}	34.67±0.69^{b}	31.98±0.74^{c}	33.87^{b}
BC	33.58±0.88^{b}	33.63±0.95^{b}	31.13±0.74^{cd}	32.78^{c}
Mix	40.52±0.60^{a}	39.48±0.86^{a}	34.05±0.45^{b}	38.01^{a}
Mean	36.49^{a}	36.11^{a}	32.19^{b}	
		Tubers weight/plant (g)		
CK	694.65±23.16^{ef}	629.89±21.97^{g}	463.00±9.91^{h}	595.85^{e}
AZ	774.93±36.38^{cd}	692.32±16.89^{ef}	643.49±30.77^{fg}	703.58^{d}
BM	794.12±27.43^{c}	721.55±29.47^{e}	689.00±25.56^{ef}	734.89^{c}
BC	879.62±27.02^{ab}	793.73±30.91^{c}	709.47±51.12^{e}	794.27^{b}
Mix	926.54±64.09^{a}	856.73±27.74^{b}	724.86±26.19^{de}	836.04^{a}
Mean	813.97^{a}	738.84^{b}	645.96^{c}	
		Weight of marketable tubers/plant (g)		
CK	575.46±17.48^{f}	499.86±25.02^{g}	348.84±20.47^{h}	474.72^{c}
AZ	647.70±13.14^{de}	673.24±23.31^{cd}	566.02±47.29^{f}	628.99^{b}
BM	672.56±35.91^{cd}	667.09±17.36^{cd}	587.09±51.09^{ef}	642.25^{b}
BC	758.36±2.74^{ab}	714.71±64.54^{bc}	637.84±26.90^{de}	703.64^{a}
Mix	785.72±34.65^{a}	725.11±24.82^{abc}	678.43±50.85^{cd}	729.75^{a}
Mean	687.96^{a}	656.00^{b}	563.65^{c}	
		Marketable tubers yield (ton/ha)		
CK	23.009±0.70^{f}	19.987±1.00^{g}	13.948±0.82^{h}	18.981^{c}
AZ	25.898±0.53^{de}	26.919±0.93^{cd}	22.632±1.89^{f}	25.150^{b}
BM	26.892±1.44^{cd}	26.673±0.69^{cd}	23.474±2.04^{ef}	25.680^{b}
BC	30.322±0.11^{ab}	28.577±2.58^{bc}	25.504±1.08^{de}	28.134^{a}
Mix	31.416±1.39^{a}	28.993±0.99^{abc}	27.126±2.03^{cd}	29.178^{a}
Mean	27.507^{a}	26.230^{b}	22.537^{c}	

Values are given as the mean ± standard deviation. Different letters indicate statistically differences according to Duncan's multiple range tests.
CK: Control, **AZ:** *Azotobacter chroococcum + Azospirillum brasilense* , **BM:** *Bacillus megaterium* , **BC:** *Bacillus circulans* **Mix:** Combined AZ+BM+BC).

5. Weight of marketable tubers/plant (g)

Marketable tubers weight per plant for various microbial treatments at different irrigation regimes during 2017/2018 and 2018/2019 seasons is presented in Table 3. The greatest value of marketable tubers per plant was obtained at 100%ETc (626.02g and 687.96g for 1st and 2nd seasons, respectively). This was followed by 80%ETc with 8.28 and 4.65 reduction percentage compared to 100%ETc. Compared with control, all microbial treatments increased fresh marketable tubers weight per plant during both seasons. Mix treatment showed the maximum weight of marketable tubers per plant (656.75g and 729.75g) over CK and other microbial treatments. Potato plants inoculated with AZ+BM+BC (Mix treatment) and received 80% of ETc showed a significant improvement over control at 100%ETc on the marketable tubers weight/plant by 27.46% and 26.01% during both seasons.

6. Marketable tubers yield (ton/ha)

Water deficits decreased significantly marketable tubers yield (ton/ha) compared to the irrigation with 100% ETc (Table 3). The greatest marketable tubers yield reduction was recorded at 60% ETc (21.29% and 18.07% during 2017/2018 and 2018/2019 seasons, respectively). However, microbial treatments showed an improvement effect on yield of marketable tuber compared with control at various irrigation regimes. Mix treatment increased marketable tubers yield by 54.75% and 53.72% in 1st and 2nd seasons, respectively. The result of interaction effects showed that inoculated potato plants with AZ+BM+BC combined at irrigation regime 100% ETc recorded greatest yield of marketable tubers (28.294 and 31.416 ton/ha during first and second seasons, respectively). The same treatment (Mix treatment) at 80% ETc recorded 7.79% and 7.71% reduction compared with 100% ETc in both seasons. However, marketable tubers yield increased by 27.47% and 26.01% compared to control at 100% ETc.

7. Total yield (ton/ha)

Various irrigation regimes and inoculation treatments, as well as their interactions, significantly affected the potato total yield (ton/ha) at $p<0.01$ during both seasons (Table 4). Irrigation regime 100% ETc showed greater average yield (29.511 and 32.546 ton/ha). Compared to 100% ETc, 80% ETc reduced total yield by 5.54% and 9.23% in 2017/2018 and 2018/2019 seasons, respectively. Moreover, microbial treatments significantly increased the total yield compared with control treatment over all irrigation regimes. More specifically, Mix treatment increased potato total yield by 30.26% and 40.31% compared to control. According to interaction effects of irrigation regimes and microbial inoculation, there was no significant different between Mix treatment at irrigation regime 60% ETc and control plants at 100% ETc during two seasons. Furthermore, with water saving up to 20%, irrigation regime 80% ETc with Mix treatment recorded only 7.59% and 7.53% reduction percentage for potato total yield compared with the same treatment at 100% ETc. Meanwhile, increased total yield by 15.20% and 23.33% compared to un-inoculated treatment (CK) at 100% ETc in the 1st and 2nd seasons, respectively.

8. Irrigation water use efficiency (IWUE, Kg/m^3)

Irrigation water use efficiency for tubers potato was obtained from the tubers potato values divided by the values of irrigation water applied (m^3/ ha). The results illustrated in Table 4 showed that the lowest values of IWUE were 5.05 and 5.33 kg/m^3 at control under irrigation with 100% ETc, while the highest (8.19 and 9.27 kg/m^3) values were obtained at application of combined bacteria (AZ+BM+BC) under irrigation with 60 % ETc, in the first and second seasons, respectively. The above results showed that bacterial inoculums application increased irrigation water use efficiency at various irrigation regimes compared to control treatment.

9. Economic productivity of irrigation water (EPIW, \$/m^3)

Economic productivity of irrigation water for tubers potato was achieved from the gross value of product (\$/ha) of potato tubers divided by the values of irrigation water applied (m^3/ha). Different irrigation regimes, inoculation treatments and their interactions significantly affected the potato EPIW (\$/m^3) at $p<0.01$ during both seasons (Table 4). In addition, the trend of EPIW was similar to the IWUE for tubers potato in both seasons. The results reflect that the lowest values of EPIW were 1.26 and 1.33 \$/m^3 at control under irrigation with 100% ETc, while the highest (2.05 and 2.32 \$/m^3) values were recorded at utilization of conjoined microbial (AZ+BM+BC) under irrigation with 60 % ETc, in the first and second seasons, respectively. The indicated results declared that microbial inoculums utilization enhanced economic productivity of irrigation water at different irrigation regimes compared to un-inoculated treatment (CK).

Table 4: Influence of different irrigation regimes, microbial inoculation and their interaction on total yield (ton/ha), irrigation water use efficiency (kg/m^3) and water productivity (\$/m^3).

Treat.	2017/2018			
	100% ETc	**80% ETc**	**60% ETc**	**Mean**
		Total yield (ton/ha)		
CK	26.801±1.30^{def}	24.447±0.86^{fg}	18.127±0.59^{h}	23.125^{d}
AZ	27.035±0.99^{def}	27.322±1.36^{de}	24.941±1.54^{efg}	26.433^{c}
BM	28.599±1.03^{cd}	26.579±1.32^{def}	24.778±1.14^{efg}	26.652^{c}
BC	31.707±1.43^{ab}	30.160±1.49^{bc}	23.523±1.63^{g}	28.463^{b}
Mix	33.412±2.71^{a}	30.875±1.28^{abc}	26.081±1.19^{defg}	30.123^{a}
Mean	29.511^{a}	27.876^{b}	23.490^{c}	
		Irrigation water use efficiency (Kg/m^3)		
CK	5.05±0.24^{g}	5.76±0.20^{ef}	5.70±0.19^{efg}	5.50^{d}
AZ	5.10±0.19^{g}	6.43±0.32^{d}	7.83±0.48^{ab}	6.45^{c}
BM	5.39±0.19^{fg}	6.26±0.31^{de}	7.78±0.36^{ab}	6.48^{c}
BC	5.97±0.27^{def}	7.10±0.35^{c}	7.39±0.51^{bc}	6.82^{b}
Mix	6.30±0.51^{de}	7.27±0.30^{bc}	8.19±0.37^{a}	7.26^{a}
Mean	5.56^{c}	6.57^{b}	7.38^{a}	
		Economic productivity of irrigation water (EPIW, \$/m^3)		
CK	1.26±0.06^{g}	1.44±0.05^{ef}	1.42±0.05^{efg}	1.37^{d}
AZ	1.27±0.05^{g}	1.61±0.08^{d}	1.96±0.12^{ab}	1.61^{c}
BM	1.35±0.05^{fg}	1.57±0.08^{de}	1.95±0.09^{ab}	1.62^{c}
BC	1.49±0.07^{de}f	1.78±0.09^{c}	1.85±0.13^{bc}	1.71^{b}
Mix	1.57±0.13^{de}	1.82±0.08^{bc}	2.05±0.09^{a}	1.81^{a}
Mean	1.39^{c}	1.64^{b}	1.84^{a}	
		2018/2019		
		Total yield (ton/ha)		
CK	27.775±0.93^{ef}	25.186±0.88^{g}	18.513±0.40^{h}	23.824^{e}
AZ	30.985±1.45^{cd}	27.682±0.68^{ef}	25.729±1.23^{fg}	28.132^{d}
BM	31.752±1.10^{c}	28.851±1.18^{e}	27.549±1.02^{ef}	29.384^{c}
BC	35.171±1.08^{ab}	31.736±1.24^{c}	28.367±2.04^{e}	31.758^{b}
Mix	37.047±2.56^{a}	34.256±1.11^{b}	28.983±1.05^{de}	33.428^{a}
Mean	32.546^{a}	29.542^{b}	25.828^{c}	
		Irrigation water use efficiency (Kg/m^3)		
CK	5.33±0.18^{f}	6.04±0.21^{e}	5.92±0.13^{e}	5.77^{e}
AZ	5.95±0.28^{e}	6.64±0.16^{d}	8.23±0.39^{b}	6.94^{d}
BM	6.10±0.21^{e}	6.92±0.28^{d}	8.82±0.33^{a}	7.28^{c}
BC	6.75±0.21^{d}	7.62±0.30^{c}	9.08±0.65^{a}	7.82^{b}
Mix	7.11±0.49^{cd}	8.22±0.27^{b}	9.27±0.34^{a}	8.20^{a}
Mean	6.25^{c}	7.09^{b}	8.27^{a}	
		Economic productivity of irrigation water (EPIW, \$/m^3)		
CK	1.33±0.04^{f}	1.51±0.05^{e}	1.48±0.03^{e}	1.44^{e}
AZ	1.49±0.07^{e}	1.66±0.04^{d}	2.06±0.10^{b}	1.74^{d}
BM	1.52±0.05^{e}	1.73±0.07^{d}	2.20±0.08^{a}	1.82^{c}
BC	1.69±0.05^{d}	1.90±0.07^{c}	2.27±0.16^{a}	1.95^{b}
Mix	1.78±0.12^{cd}	2.06±0.07^{b}	2.32±0.08^{a}	2.05^{a}
Mean	1.56^{c}	1.77^{b}	2.07^{a}	

Values are given as the mean ± standard deviation and different letters indicate statistically differences according to Duncan's multiple range tests.
CK: Control, **AZ***: Azotobacter chroococcum + Azospirillum brasilense*, **BM***: Bacillus megaterium*, **BC***: Bacillus circulans* **Mix:** Combined AZ+BM+BC).

10. Protein yield (kg/ha)

There were highly significant differences among irrigation regimes and microbial treatments as well as their interaction effects in the yield of protein (Fig. 3). In total, the maximum protein yield (428.27 and 511.01 kg/ha during first and second seasons, respectively) was produced from irrigation regime 100% ETc and decreased with increasing water deficit. Moreover, the results showed that inoculation treatments increased significantly protein yield compared to control in both seasons. The highest protein yield was obtained from potato plants subjected to Mix treatment (399.92 and 482.96 kg/ha during 2017/2018 and 2018/2019 seasons, respectively). On the other hand, control treatments recorded only, 289.41 and 320 kg/ha during 1st and 2nd seasons, respectively. According to the interaction effects, highest protein yield (477.24 and 572.15 kg/ha) in both seasons was recorded when potato plants watered with 100% ETc and inoculated with combined treatment (AZ+BM+BC) with no significant difference with inoculation with BC in two seasons.

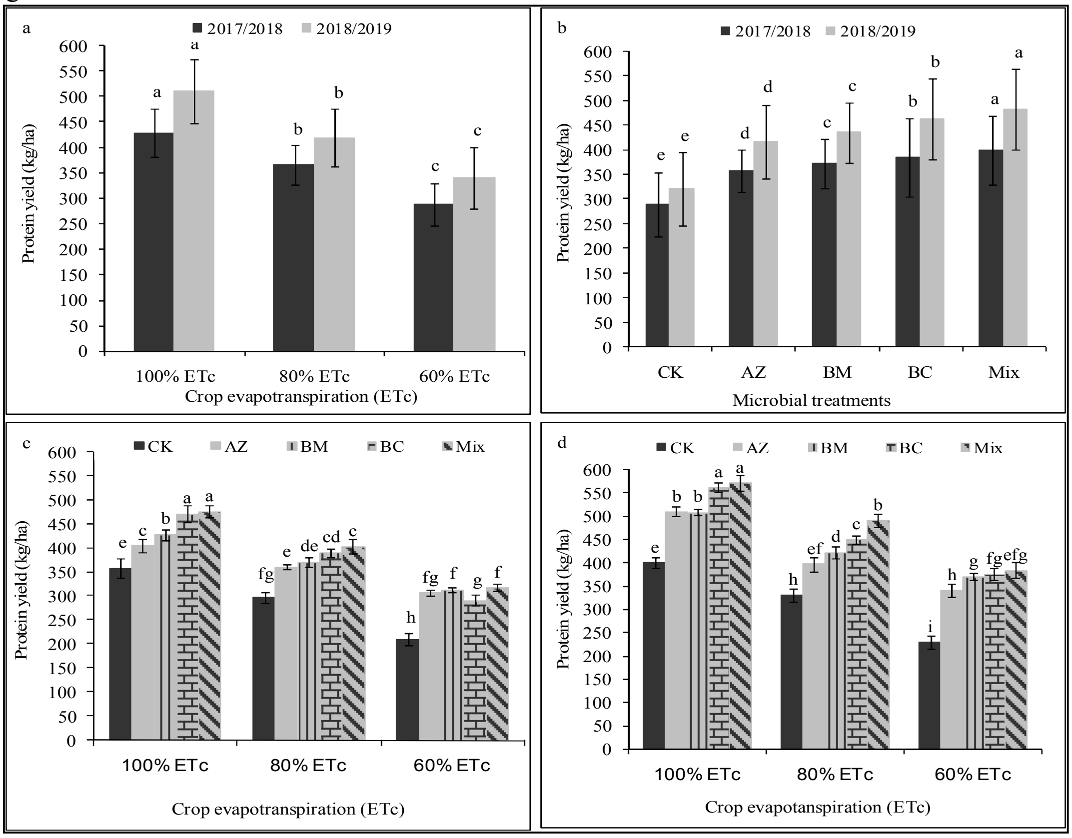

Fig. 3: Influence of irrigation regimes (a), microbial treatments (b) and their interaction during 2017/2018 (c) and 2018/2019 (d) seasons on the protein yield (kg/ha). Data are presented as means ± SDs and the different upper letters indicate significant differences at $P < 0.05$ level according to Duncan's multiple range tests, (n = 15 in irrigation regimes treatments, n = 9 in microbial treatments and n = 3 in their interaction treatments).

11. Starch yield (kg/ha)

The results showed a highly significant difference on the starch yield regarding the effect of various irrigation regimes and microbial treatments (Fig. 4). There was a decrease in starch yield with increased imposing of water deficit. Furthermore, inoculation treatment enhanced the production of starch and alleviated the negative impact of water shortage on starch synthesis compared to untreated plants with bacteria. The starch reduction percentage in control treatment ranged from 20.75% compared to AZ treatment to 31.05% compared to Mix treatment in the first season and ranged from 25.05% to 37.22% in second season compared to same treatments, respectively. Moreover, Mix treatment under irrigation regime 100% ETc showed the highest starch yield in two seasons (654.79 and 775.72 kg/ha during 1st and 2nd seasons, respectively).

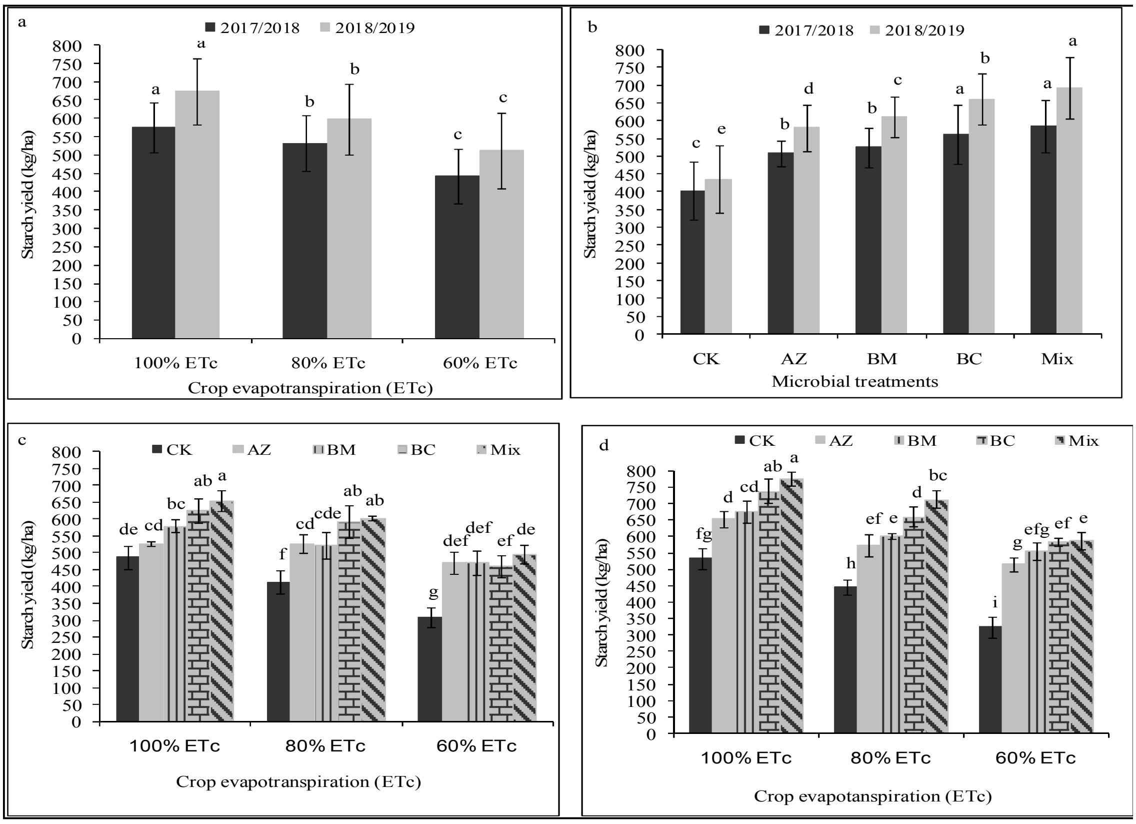

Fig. 4: Influence of irrigation regimes (a), microbial treatments (b) and their interaction during 2017/2018 (c) and 2018/2019 (d) seasons on the starch yield (kg/ha). Data are presented as means ± SDs and the different upper letters indicate significant differences at $P < 0.05$ level according to Duncan's multiple range tests (n = 15 in irrigation regimes treatments, n = 9 in microbial treatments and n = 3 in their interaction treatments).

12. Dry tubers yield (ton/ha)

Various irrigation regimes and microbial treatments, as well as their interactions, significantly affected the dry tubers yield (ton/ha) at $p<0.01$ during both seasons (Table 5). The result of the main factor effect, irrigation regimes, showed that the greater average of dry tubers yield (ton/ha) was obtained when potato plants irrigated with 100% ETc (5.076 ton/ha and 5.747 ton/ha during 2017/2018 and 2018/2019 seasons, respectively). Meanwhile, among microbial treatments, combined treatment (AZ+BM+BC) recorded the highest value of dry tubers yield (5.170 ton/ha and 5.900 ton/ha during 1st and 2nd seasons, respectively) with increase percentage of 36.28 and 48.09 in both seasons compared to control. This was followed by treated plants with BC (4.918 ton/ha and 5.616 ton/ha). Regarding to the interaction effects, Mix treatment under irrigation regime 100% ETc had the greatest value of dry tubers yield during two seasons (5.755 ton/ha and 6.567 ton/ha). Moreover, irrigation potato plants with 80% ETc and inoculation with combined microbial recorded only 7.04% and 7.72% reduction percentage compared to same microbial treatment under 100% ETc. However, obtained 18.74% and 27.63% increase percentage compared to control treatment under 100% ETc.

13. Nitrogen uptake (kg/ha)

The statistical analysis of nitrogen uptake results revealed that there were significant differences among different irrigation regimes, inoculation treatments and their interaction at $p < 0.01$ (Table 5).

Table 5: Dry tubers yield (ton/ha), nitrogen uptake (kg/ha), phosphorus uptake (kg/ha) and potassium uptake (kg/ha) as effected by various irrigation regimes and different microbial treatments as well as their interaction.

Treat.	2017/2018			
	100% ETc	**80% ETc**	**60% ETc**	**Mean**
		Dry tubers yield (ton/ha)		
CK	4.476±0.24^{ef}	3.960±0.20^{g}	2.944±0.09^{h}	3.794^{d}
AZ	4.654±0.12^{de}	4.677±0.10^{de}	4.233±0.12^{fg}	4.521^{c}
BM	5.007±0.17^{cd}	4.592±0.27^{ef}	4.217±0.23^{fg}	4.605^{c}
BC	5.488±0.26^{ab}	5.211±0.31^{bc}	4.055±0.23^{g}	4.918^{b}
Mix	5.755±0.16^{a}	5.315±0.12^{bc}	4.441±0.03^{ef}	5.170^{a}
Mean	5.076^{a}	4.751^{b}	3.978^{c}	
		Nitrogen uptake (kg/ha)		
CK	57.41±3.33^{e}	47.77±1.81^{fg}	33.74±1.88^{h}	46.31^{e}
AZ	64.70±2.23^{c}	57.76±0.89^{e}	49.08±1.06^{fg}	57.18^{d}
BM	68.61±1.78^{b}	59.55±1.53^{de}	50.30±0.69^{f}	59.49^{c}
BC	75.54±2.64^{a}	62.58±1.35^{cd}	46.73±1.92^{g}	61.62^{b}
Mix	76.36±2.09^{a}	64.66±2.57^{c}	50.94±1.14^{f}	63.99^{a}
Mean	68.52^{a}	58.46^{b}	46.16^{c}	
		Phosphorus uptake (kg/ha)		
CK	21.10±1.24^{efg}	18.23±0.96^{h}	13.06±0.42^{i}	17.46^{c}
AZ	22.64±0.52^{de}	22.24±1.85^{de}	19.43±1.62^{fgh}	21.44^{b}
BM	24.48±1.73^{cd}	21.52±1.42^{ef}	19.45±0.96^{fgh}	21.82^{b}
BC	27.09±1.75^{ab}	24.67±1.23^{bcd}	18.76±1.39^{gh}	23.51^{a}
Mix	27.99±1.51^{a}	25.22±1.63^{bc}	20.50±1.02^{efgh}	24.57^{a}
Mean	24.66^{a}	22.38^{b}	18.24^{c}	
		Potassium uptake (kg/ha)		
CK	111.84±9.06^{de}	87.53±4.54^{fg}	53.32±4.49^{h}	84.23^{d}
AZ	125.89±10.23^{bc}	108.24±7.12^{e}	76.68±8.31^{g}	103.60^{c}
BM	127.94±8.07^{bc}	113.83±7.05^{de}	87.35±0.58^{fg}	109.71^{bc}
BC	137.27±6.70^{ab}	122.88±7.47^{cd}	86.46±9.35^{fg}	115.54^{ab}
Mix	143.24±3.49^{a}	121.39±10.07^{cd}	95.57±5.08^{f}	120.07^{a}
Mean	129.24^{a}	110.77^{b}	79.88^{c}	
		2018/2019		
		Dry tubers yield (ton/ha)		
CK	4.748±0.15^{e}	4.160±0.12^{g}	3.043±0.13^{h}	3.984^{e}
AZ	5.509±0.17^{c}	4.881±0.15^{de}	4.476±0.12^{f}	4.956^{d}
BM	5.669±0.16^{c}	5.111±0.14^{d}	4.807±0.12^{e}	5.195^{c}
BC	6.243±0.20^{b}	5.612±0.16^{c}	4.992±0.19^{de}	5.616^{b}
Mix	6.567±0.19^{a}	6.060±0.10^{b}	5.072±0.06^{d}	5.900^{a}
Mean	5.747^{a}	5.165^{b}	4.478^{c}	
		Nitrogen uptake (kg/ha)		
CK	64.11±1.75^{e}	53.05±2.35^{h}	36.77±2.19^{i}	51.31^{e}
AZ	81.63±1.56^{b}	63.53±2.37^{ef}	54.60±2.13^{h}	66.58^{d}
BM	81.51±1.09^{b}	67.79±2.03^{d}	59.50±1.23^{g}	69.60^{c}
BC	90.01±1.74^{a}	72.13±1.42^{c}	60.24±2.00^{fg}	74.13^{b}
Mix	91.54±2.81^{a}	78.73±2.18^{b}	61.55±2.65^{efg}	77.27^{a}
Mean	81.76^{a}	67.05^{b}	54.53^{c}	
		Phosphorus uptake (kg/ha)		
CK	21.16±0.93^{de}	18.17±0.77^{f}	12.77±0.51^{g}	17.37^{d}
AZ	25.41±0.67^{c}	21.95±1.27^{d}	19.44±1.32^{ef}	22.27^{c}
BM	26.28±1.01^{c}	22.85±1.03^{d}	21.03±1.18^{de}	23.39^{c}
BC	29.04±1.17^{ab}	25.22±2.20^{c}	21.82±0.81^{d}	25.36^{b}
Mix	30.34±1.21^{a}	27.29±1.22^{bc}	22.17±1.25^{d}	26.60^{a}
Mean	26.44^{a}	23.09^{b}	19.45^{c}	
		Potassium uptake (kg/ha)		
CK	113.44±7.78^{fg}	87.80±5.28^{ij}	53.38±4.64^{k}	84.87^{d}
AZ	141.44±7.67^{bc}	108.09±3.86^{g}	78.50±5.91^{j}	109.34^{c}
BM	139.51±7.12^{c}	119.54±4.13^{ef}	95.17±3.97^{hi}	118.07^{b}
BC	151.20±6.34^{ab}	127.96±9.09^{de}	102.67±6.31^{gh}	127.28^{a}
Mix	157.54±4.86^{a}	133.46±7.66^{cd}	104.61±6.03^{gh}	131.87^{a}
Mean	140.62^{a}	115.37^{b}	86.86^{c}	

Values are given as the mean ± standard deviation. Different letters indicate statistically differences according to Duncan's multiple range tests.

CK: Control, **AZ:** *Azotobacter chroococcum + Azospirillum brasilense* , **BM:** *Bacillus megaterium* , **BC:** *Bacillus circulans* **Mix:** Combined AZ+BM+BC).

Compared to other irrigation regimes, 100% ETc showed the highest nitrogen uptake in both seasons (68.52 kg/ha and 81.76 kg/ha). In generally, inoculation treatments compared to control increased nitrogen uptake highly significant. Mix treatment enhanced nitrogen uptake by 38.18% and 50.59% compared to control. The combination of 100% ETc and Mix treatment induced greatest nitrogen uptake in both seasons (76.36 kg/ha and 91.54 kg/ha). Additionally, same inoculation treatment (AZ+BM+BC) under irrigation regime 80% ETc obtained reduction percentage of 15.32% and 13.99% compared to irrigation regimes 100% ETc. However, increased nitrogen uptake by 12.63% and 22.80% in the 2017/2018 and 2018/2019 seasons, respectively, compared to control under irrigation regime 100% ETc.

14. Phosphorus uptake (kg/ha)

The statistical analysis of phosphorus uptake results reported that there were significant differences among various irrigation regimes and microbial treatments at $p < 0.01$ (Table 5).Plants irrigated with 100% ETc had the highest phosphorus accumulation compared with other irrigation regimes, which recorded 24.66 kg/ha and 26.44 kg/ha in 2017/2018 and 2018/2019 seasons, respectively (Table 5). Moreover, the results of the microbial treatment effect indicated that plants treated with Mix microbial treatment accumulated highest phosphorus amounts during both seasons (24.57 kg/ha and 26.60 kg/ha) with 40.72 % and 53.14 increase percentage compared to un-inoculated treatment (CK). The results of interaction effect showed that potato plants under irrigation regime 100% ETc and treated with combined microbial accumulated more phosphorus than other treatments (27.99 kg/ha and 30.34 kg/ha during first and second seasons, respectively). Phosphorus accumulation amount under irrigation regime 80% ETc and Mix treatment recorded 19.53% and 28.97% increase percentage compared to control treatment under irrigation regime 100% ETc.

15. Potassium uptake (kg/ha)

The statistical analysis of potassium uptake results conducted that there were significant differences among different irrigation regimes and bacterial treatments at $p < 0.01$ (Table 5). The total amount of potassium accumulation during 2017/2018 and 2018/2019 seasons was higher under irrigation regime 100% ETc than 80% ETc and 60% ETc, which were 129.24 kg/ha and 140.62 kg/ha, respectively (Table 5). This was followed by irrigation regime 80% ETc (110.77 kg/ha and 115.37 kg/ha during 1st and 2nd seasons, respectively. Over different irrigation regimes, microbial inoculation enhanced potassium accumulation compared to control treatment. Mix treatment recorded highest potassium quantity (120.07 kg/ha and 131.87 kg/ha), with no significant difference with BC treatment in both seasons (115.54 kg/ha and 127.28 kg/ha). According to the interaction effects between various irrigation regimes and different microbial treatments, Mix treatment under irrigation regime 100% ETc had the greatest value of potassium accumulated amount during both seasons (143.24 kg/ha and 157.54 kg/ha), with no statistically significant differ with BC under the same irrigation regime. Furthermore, treated potato plants under irrigation regime 80% ETc with combined microbial give 121.39 kg/ha and 133.46 kg/ha potassium amount, with 8.54 % and 17.65% increase percentage compared to control under irrigation regime 100% ETc. This was not significant differ than BC under irrigation regime 80% ETc during both seasons.

Discussion

There are often different responses among crops to water deficit or drought stress. Potato considered as drought sensitive crop and the decrements of its productivity are related with decreasing required water amount during different growth stages. Previous reports concluded that water deficit cause yield reduction by decreasing the growth of crop canopy and biomass (Fabeiro *et al.*, 2001; Yuan *et al.*, 2003; Onder *et al.*, 2005; Kaur *et al.*, 2005). The variations in irrigation water applied among different growth stages might be due to the loss of moisture were mostly by soil surface evaporation at the beginning of the growth stage because potato canopy has not established yet. However, a gradual increase in water consumption was recorded due to plant develop and the increase in irrigation water applied under 100% ETc could be attributed to the increase in direct evaporation. Therefore, the seasonal irrigation water applied is higher under 100% ETc followed by 80 and 60% ETc for potato during the two growth seasons. These results are in the same trend with those reported by Abdalla *et al.* (1990); El-Koliey *et al.* (2001); Eid *et al.* (2013), Ati *et al.* (2013) and Badawy *et al.* (2019).

Potato yield was significantly increased by inoculated potato plants with various bacteria compared to control treatment under various irrigation regimes. Several studies indicated the positive effects of bio-fertilizer on growth of plant and increase the crop yield significantly compare to non-inoculated plants (Hammad and Abdel-Ati 1998; Atimanav and Adholeya 2002; Clarson 2004; Malboobi *et al.* 2009; Abou El-Khair and Nawar 2010; Abou-Zeid Bakry 2011; El-Sayed *et al.* 2015). The obtained results are in accordance with Zaghloul (2002) who found that the growth parameters were significantly increased potato tuber inoculated by *B. megaterium*. In the same trend, *Azotobacter* spp. and *Azospirillum* spp., by producing some phytohormones such as auxin, cytokinin, gibberellins and abscisic acid, can promote plant growth and enhance plant productivity (Bottini *et al.* 2004). Moreover, *Azotobacter* spp. could enhance plant growth and production because it can help the plant to fight against many plant pathogens for the reason that it can also produce antifungal compounds (Jen-Hshuan 2006). The positive effects due to use microbial inoculation might be attributed to enhance the efficiency of water and nutrients absorption (Dalla Santa *et al.* 2004; Mohammadi *et al.* 2013). Bottini *et al.* (2004) mentioned that *Azospirillum* spp. inoculation enhance plant growth through increase the number of lateral roots and root hairs results in increase the root surface, which results in enhance nutrient uptake and improve water status. Lin (1991) indicated that treated soil with microorganisms improve soil structure and become less compact, more friable and better drained, and this could lead to provided better growing conditions for potato growth and tuber production. Previous studies reported that the positive effect of microorganism inoculation on yield and yield component could be due to enhance root growth and functions, increasing mineral uptake into the plant, phytohormones production i.e. IAA, GAs and cytokinin, also cause reduction of abscic acid (Stancheva *et al.* 1995; Elhakim *et al.* 2016). In addition, Kawther *et al.* (2002) indicated that phytohormones play important role in plant growth stimulation. Also, El-Sayed *et al.* (2015) reported that using organic and bio-fertilizer increased significantly the marketable tubers. Production of plant growth regulators by microorganism could increase the positive effect of bio-fertilizers in increasing total and marketable potato yield (Norman *et al.,* 2003).

The trends of irrigation water use efficiency are negatively correlated with the total amount of irrigation water, total tuber yield and dry biomass of potato plants (Yuan *et al.* 2003; Abou El-Khair *et al.,* 2011). The obtained trends of IWUE are in general agreement with those reported by Al-Aubiady (2005); Mahmoud and hafez (2010); Abd-All *et al.* (2017); Khan *et al.* (2017) and Badawy *et al.* (2019). Furthermore, in melon, IWUE did not increased by increasing irrigation levels as reported by Al-Mefleh *et al.* (2012) and Yaseen *et al.* (2014); and lower irrigation treatments induce higher values of IWUE (Abd El-Mageed and Semida 2015). This was confirmed by Ertek *et al.* (2004) who concluded that the highest values of IWUE for summer squash were obtained under the lowest irrigation conditions. In the same direction, El-Gindy *et al.* (2009) showed that lower water amounts (60% of ETc) recorded higher IWUE than drip-irrigated summer squash with higher water amounts (80% ETc). In contrast, Cantore *et al.* (2014) reported that IWUE was not influenced by the applied supplementary irrigation, which the IWUE values were 10.7 and 10.6 for full irrigation and 50% irrigation.

The high tuber quality could be comrade to height absorbance and effective use of nutrients by potato plants for proteins synthesis and carbohydrates metabolism, which are answerable to dry matter accumulation (Jatav *et al.,* 2013). The obtained results of protein and starch yield, dry tubers yield, as well as nitrogen, phosphorus and potassium uptake, were influenced negatively by water deficit and increased significantly when potato plants inoculated by bacteria compared to control. The increases in the protein yield, starch yield, dry tubers yield might be attributed to the high content of leaves from the nitrogen, phosphorous and potassium elements that donate efficiently to the protein and starch composition as well as increase in total dissolved solids in the potato tubers (El-Zehery, 2019). Nitrogen is directly included in the synthesis of amino acids, which are the essential compounds for protein synthesis (Barak, 1999). Phosphorous is enters inside the synthesis of DNA and RNA, which directly influences protein synthesis and amelioration of crop yield and quality (Scalenghe *et al.,* 2012). In addition, potassium effects the irrigation economy and plant growth through its effects on water absorbance, root development, upkeep of turgor, stomatal regulation, transpiration, enzyme activation and carbohydrate metabolism, as well as potassium enhancement the efficiency of nitrogen uptake and consequently increases in protein synthesis. (Mfilinge *et al.* 2014; Elhakim *et al.* 2016).

The decrements of N and P under water deficit conditions are related with decreasing of water potential in rhizosphere and cells of the plant (Mamnabi *et al.* 2020). In addition, Bista *et al.* (2018)

stated that drought decreases the concentration of nitrogen and phosphorous in plants consequently decreasing productivity. On the other side different biochemical and physiological processes are altered by water deficit, such as photosynthesis (Pagter *et al.,* 2005) and the metabolism of amino acids, protein, carbohydrates and other organic compounds (Šircelj *et al.,* 2005). In this respect, Abou El-Khair *et al.* (2011) declared that irrigation by water quantity of 2976 or 4167 m^3/ha recorded the highest values of carbohydrates, starch, dry matter, N and P content in tuber tissues as compared with the lowest irrigation water quantity (1786 m^3/ha).

The increases in N, P and K uptake by potato tubers inoculated by *Azotobacter chroococcum* + *Azospirillum brasilense* attributed to the higher absorption of available NPK, that's might be were abundantly usable in soil. In addition, species of *Azotobacter* and *Azospirillum*, these are free-living nitrogen fixing bacteria are obligate aerobes that fix atmospheric nitrogen and transferring them to plant as usable forms in the soil, thereby converting them available to plants without symbiosis. Furthermore, it has an ability to fix nitrogen between 20-40 kg/ha and save N-fertilizer in some cereals, vegetable and legume crops such as maize, sorghum, sugarcane, potato, onion and pigeonpea (Bhattacharjee and Dey, 2014; Jehangir, *et al.* 2017). These quantity of fixed nitrogen was important, especially in these current investigation with calcareous soils contained 91.1% sand, only 0.01% total nitrogen (measured by micro-kjeldahl procedure) and high pH value 8.44 (measured by a glass electrode in 1:1 soil water suspension). On the other hand, potato crop grown in arid region in these currant investigation was fertilized by modest N-fertilizer level (only, 214.3 kg/ha). On the other side, N-fixer bacteria can produced growth-regulating materials and enhance crop yield by 15 - 30% (Singh and Singh, 2011). Moreover, these N-fixing bacterial species can significantly increment other nutrients available to the plant (Mohammadi *et al.* 2013). In this respect, Mahendran *et al.* (1996) showed that inoculation with *Azospirillum* sp and *B. megaterium* increased potato tubers dry matter contents and NPK uptake.

Usually soil pH is the most crucial chemical characteristic influencing nutrient precipitation, solubility, availability and sorption (Basta *et al.* 2005). Optimum availability to plants of both applied and natural phosphorus as well as nitrogen and potassium is in the pH ambit of 6.0 to 7.5. At higher pH values, especially in calcareous soils calcium and magnesium cations react with phosphate anions to form insoluble phosphate compounds that cannot be absorbed by crops (Wahba *et al.* 2019). Taking into consideration that, the current investigation soil was sandy calcareous soils, with 29.80% total $CaCO_3$ (measured by a Schreiber calcimeter) and pH was 8.44.Thus, this physico-chemical properties, was reflected on available phosphorus (only 7.01 ppm of available phosphorus, measured coloremetrically. by the stannous chloride phosphomolybdic-sulfuric acid method as dscrepted by Jackson, (1973). On the other hand, moves of phosphorus in calcareous soils is very little from the point of application. Consequently, P availability and uptake by plants will be limited (Rubiez *et al.* 1991). On the other side, potassium in the soil emerges mostly as silicate minerals, which are unavailable to plants. These minerals are created available only when they are solubilized or slowly weathered (Ju *et al.,* 2018). The additions in P, K and N uptake by potato tubers inoculated by *Bacillus megaterium* and/or *Bacillus circulans* attributed to the higher absorption of available P, K and N, that's might be were abundantly available in soil.

Phosphate solubilizing bacteria (PSB) can solubilize the fixed phosphorus in calcareous soil and other soils. PSB have the capability to transfer chemical unavailable P form to soluble forms H_2PO4^- and HPO_4^{-2}, through the process of enzymes, organic and inorganic acids production (low molecular weight organic acids, usually ketogluconic and gluconic acids). Carboxy and hydroxy groups of acids chelate cations (Ca, Mg, Al and Fe) and reduced the pH of the soil and create the dissolution of fettered forms of phosphate producing them available to plants as well as other nutrients will be more available (Han *et al.* 2006; Yang *et al.* 2009; Mohammadi and Sohrabi 2012; Ju *et al.* 2018). In addition, bacteria are more efficient in P solubilization than fungi (Mohammadi and Sohrabi, 2012). *Bacillus megatherium* and *Bacillus circulans* could be commit as the most important strains (Mohammadi and Sohrabi, 2012). Ju *et al.* 2018 reported that some phosphate solubilizing microbial like *Bacillus* species has been found to solubilize phosphorus and potassium as well as mobilize phosphorus and potassium. Thus, more phosphorus and potassium uptake is prospective especially with potato shallow rooting system (Stark *et al.,* 2004). Opena and Porter, (1999) mentioned that around 85% of potato root is intensive in the upper 30 cm soil layer. In this respect, Abd El-Daym *et al.* (2019) conducted that combined application of different sources of nitrogen fertilizers (organic and inorganic N) with biofertilizer significantly enhanced contents of protein, starch, dry matter, nitrogen, phosphorus, potassium and calcium in potato tubers as well as increased soil nutrient contents, such as usable N (NH_4-N and NO_3-N), usable P and exchangeable K content. Furthermore El-Zehery, (2019) suggested that organic fertilizer + biofertilizer (*Bacillus*, *Azospirillum*, *Azotobacter* and *Pseudomonas* spp) guide to a significant increment in protein, starch, dry matter, nitrogen, phosphorus and potassium content in potato tubers as compared with control (without organic fertilizer or biofertilizer).

Potassium solubilizing bacteria like as *Bacillus* Spp solubilize silicates by making organic acids, which motive the decomposition of silicates and assist in the transit of metal ions thereby making them usable to plants (Ju *et al.,* 2018). Furthermore, increase in potassium uptake might be attributed to the role of microorganisms in providing great amounts of water-soluble and amorphous potassium which was reflected in plant uptake (Afify and Bayoumy, 2001). Thus, Potassium solubilizing microbial are wide uses as bio-fertilizers. In this respect, Elhakim *et al.* (2016) hypothesis that, application of K fertilizer at 286 kg K_2O/ha with application of potassium biofertilizer *Bacillius Circulans* gave the highest mean value of potassium content in leaves, starch and potassium content in potato tubers. In addition, Elkholy *et al.* (2012) observed that inoculation with *Bacillus circulans* as silicate dissolving bacteria with different potassium sources increased tuber content of protein and carbohydrate as well as plant shoot, plant tubers and soil usable content of N, P, K, Fe, Mn, Zn and Cu compared to the control (without K sources).

Generally, use of bacteria could increase the nutrient uptake through some modification of rhizosphere physic-chemical properties such as enhancing soil cation exchange capacity and some other biochemical responses in root tissues (Adhikary, 2012). Improve of root nutrient absorption under various environmental conditions i.e. water stress might be because the reason of PGPRs treatments increased the photo assimilate translocation to the root tissues. PGPRs could be increase the activity of some important enzymes involved in nitrogen metabolizing like nitrate reductase (NR), thereby improving the N content under water deficit (Ansari and Ahmad, 2019).

In respect to the obtained results in the current investigation, the extend in yield and yield compounds, dry tubers yield, protein and starch yield, and NPK uptake increases in the inoculation treatments compared to control treatments under different irrigation regimes might be attributed to the beneficial effects of microorganisms and their important roles in supplying plants with nutrients, plant growth regulators and production of some phytohormones and antifungal. Consequently, use of microbial inoculation could be effective method to alleviate the impact of water stress on plant growth and crop production.

Conclusion

Increasing water deficit induced decrease in all studied parameters exhibit irrigation water use efficiency and economic productivity of irrigation water. However, with application of microbial inoculation potato growth, total and marketable yield, dry tubers yield, protein and starch yield, and uptake of N, P, and K were enhanced under various irrigation regimes compared to control. Especially the combined microbial treatment (AZ+BM+BC) increased significantly the above mentioned characters.

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