DETERMINATION OF WATER CONSUMPTION OF POTATO UNDER IRRIGATION SYSTEMS AND IRRIGATION INTERVALS BY USING POLYMERS AND BIO-FERTILIZERS IN DESERT SOILS

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Abstract

Two field experiments were conducted during the spring season 2020 in Karbala governorate, to study the effect of sprinkler and surface drip irrigation systems to determine water consumption of potatoes and irrigation intervals using polymers and bio-fertilizers in desert soils. The experiment included three factors: 1-Irrigation system surface drip T_1 and sprinkler T_2, 2- The Irrigation interval: every 2 days I_1, 4 days I_2 and 6 days I_3, 3-Addition of soil conditioners: control without any addition C, bio-organic fertilizers (seek) B, polymer (zeba) P, and polymer+ bio-organic fertilizers P+B. The experiment was designed according to the nested design with three replicates. Potato tuber class (Hermosa) rank E was planted. The results showed that the operating pressure of 50-150 kPa was drip and sprinkler irrigation, respectively. Irrigation interval treatment I_1 also obtained the lowest added water depth of 212.64 and 486.70 mm at the drip and sprinkler irrigation systems, respectively. Moreover, the actual consumptive use ETa values for irrigation interval I_1, I_2, and I_3 at drip irrigation were 276.44, 428.31, and 593.04 mm, respectively. Though at sprinkler irrigation were 550.50, 959.46, and 1385.08 mm for irrigation intervals I_1, I_2, and I_3, respectively. The highest values of crop coefficient at tuber formation and filling stage were 0.66, 0.79, 1.06, 1.86, 3.42, and 4.73 for the irrigation interval I_1, I_2, and I_3, respectively, at the drip and sprinkler irrigation systems.

Key words: sprinkler irrigation; surface drip irrigation; water consumption; polymers.
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مجلة العلوم الزراعية العراقية -2023 :54(5):1351-1363 اللامي وآخرون

تحديد الاستهلاك المائي للبطاطا تحت نظم ري وفواصل إرواء بأستخدام البوليمرات والمخصبات الحيوية في الترب الصحراوية

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المستخلص

أجريت تجربتين حقليتين خلال الموسم الربيعي 2020 في محافظة كربلاء، لدراسة تأثير أنظمة الري بالرش والتنقيط السطحي لتحديد الاستهلاك المائي للبطاطا وفواصل أرواء بإستخدام البوليمرات والمخصبات الحيوية في الترب الصحراوية. شملت التجربة دراسة ثلاثة عوامل: 1- نظام الري: التنقيط السطحي T_1 والرش T_2. 2- فاصلة الإرواء بثلاث معاملات: الارواء كل 2 أيام I_1 و4 أيام I_2 و6 أيام I_3. 3- إضافة محسنات التربة بأربعة معاملات: المقارنة بدون اي اضافة C ومخصبات حيوية عضوية B وبوليمر P وبوليمر+مخصبات حيوية عضوية رمزها P+B. صممت التجربة وفق التصميم التجميعي بثلاث مكررات. زرعت تقاوي البطاطا صنف (Hermosa) رتبة E. أظهرت النتائج اعتماد الضغط التشغيلي 50 150 كيلوباسكال عند الري بالتنقيط والري بالرش على الترتيب. كما حصلت معاملة فاصلة الإرواء I_1 على اقل عمق ماء مضاف 212.64 و486.70 مم عند نظامي الري بالتنقيط والرش، على الترتيب. في حين بلغت قيم الاستهلاك المائي الفعلي لفاصلة الإرواء I_1 وI_2 وI_3 عند الري بالتنقيط 276.44 و428.31 و593.04 مم، على الترتيب. وعند الري بالرش بلغت 550.50 و959.46 و1385.08 مم لفواصل الإرواء I_1 وI_2 وI_3، على الترتيب. وبلغت اعلى قيم لمعامل المحصول في مرحلة تشكل وملء الدرنات 0.66 و0.79 و1.06 و1.86 و3.42 و4.73 لفاصلة الإرواء I_1 وI_2 وI_3، على الترتيب عند نظامي الري بالتنقيط والري بالرش.

الكلمات المفتاحية: الري بالرش، الري بالتنقيط السطحي، الاستهلاك المائي، بوليمر.
***البحث مستل للباحث الأول**

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INTRODUCTION

Water resources constitute the basic lifeline for the environment of arid and semi-arid areas. Water resources in Iraq have faced many threats, especially in the second half of the last century, as large areas dried up and water resources shrank due to the establishment of irrigation projects in Syria, Turkey, and Iran. The problem of desertification is also one of the main challanges that have become a threat at present, as it contributes to the reduction of agricultural lands and their low productivity in areas with arid and semi-arid climatic characteristics. Iraq is exposed to a real problem that threatens its food security through the low productivity of arable lands, as a result of salinization and waterlogging of soils, deterioration of vegetation cover, encroachment of moving sand dunes, and the activity of dust storms. Climate predictions indicate that the intensity, frequency, and duration of droughts will increase (25), which have a serious impact on the yield of crops, especially those that need irrigation, such as vegetables and other horticultural crops. Thus, increasing the water use efficiency (WUE) of crops and saving water resources has become of strategic importance. Drip irrigation is one of the most important modern irrigation methods in terms of irrigation efficiency and reducing water losses, as it works to prepare water without any losses, as it is added accurately and calculated for the root area (3). That the moisture content to increased at the drip source, and the values of the moisture content decreased by moving away from the drip source vertically and horizontally (9,12). The study was conducted by (15) showed that drip irrigation recorded a significant increase in potato yield with 23 and 7% in the two seasons (2009 and 2010), respectively compared to the sprinkler irrigation system when using four irrigation treatments 50, 75, 100, 125% of ETp with two irrigation systems (sprinkler and drip) with sandy soil and under arid and semi-arid conditions. The yield was increased by 125% for the two seasons with an increase in the amount of irrigation water. The seasonal water requirements of the crop under the drip irrigation system were 350 and 386 mm for the two seasons, respectively, and the highest value for WUE was 11.37 kg m^{-3} with 100%, Irrigation scheduling is the process of determining planning irrigation periods, the amount of water needed by the crop, the speed of water application (the rate of use), and the number of irrigation times. The maximum economic response to irrigation can only be achieved through a practical and effective scheduling system (36). Inadequate irrigation leads to water stress, which in turn reduces production (38). Polymer is a compound with a high molecular weight ranging from 1,000 to more than 100,000 organic or inorganic molecules or both, natural or synthetic. Polymer is used in many applications, including agricultural applications (8). Super-absorbent polymers (SAPs) are compounds that have the ability to absorb water in very large quantities relative and re-release it when the plant needs it. Besides, it can contribute to maintion of water for long periods, to reduce deep seepage and loss of nutrients in the soil and increase water and fertilizer use efficiency (16, 40). The application of the polymer leads to bind soil particles and enhane the sap rates and permeability, and reduce the total amount of water required for irrigation by 15-50% (29). The use of SAPs in drought conditions prevents the loss of water and nutrients, creates good conditions for growth and leads to an increase in the yield of the water consumed (13,27). It was also found (6) through a field experiment in Anbar Governorate - Spring 2018 in sandy soil to study the role of perlite, the amount of irrigation and its periods in water consumption with the growth and productivity of potatoes using three additive treatments 0, 4 and 8% of the soil volume and with two irrigation treatments At 100 and 50% of the net irrigation depth at 3 and 6 day irrigation intervals. The results showed the highest values for plant height, leaf area, dry weight and total yield 66.5 cm, 64 dcm $plant^{-1}$, 86.870 g $plant^{-1}$, and 28 ton ha^{-1}, respectively for perlite at 8% addition level, and irrigation. In 3 days at 100% level. Moreover, the plant dry weight was decreased by 16.27% at irrigation every 6 days, 50%, and at 8% of perlite compared to irrigation every 3 days and 100% at the level of perlite. The water consumption of potato crop was 472 and 235 mm at irrigation every 3 days with the addition of 100 and 50% of the net irrigation depth, respectively, and the highest water use efficiency was 21.26 kg m^{-3} when perlite level 8% was added. Biological fertilizers are one of the most important paths to achieve clean agriculture and a basic ingredient for soil health. It contributes to supplying the plant with its nutritional needs, as well as improving soil fertility. That the biological fertilizers are as living organisms added to seeds or soil that stimulate plant growth and increase the availablity of nutrients. It has may or role in reducing mineral fertilizers and are considered environmentally friendly and non-polluting (28). Recent studies have given importance to the use of biofertilizers, which reduce the use of chemical fertilizers by approximately 40-50% contribute to sustainable agriculture. Also, the use of biofertilizers leads to an increase in plant growth and crop productivity to more than 30% (35). Several studies have been carried out in Iraq and many regions in the world on the feasibility of using biofertilizers, including the study of (1) in Anbar Governorate in silty loam soil. They were found that the single fertilization of bacteria and fungi biofertilizers and levels of mineral fertilizer significantly increased the characteristics of the vegetative growth parameters of the Potato crop. On the other hand, (2) was carried out a field study to evaluate two types of biofertilizers, which Mycorrhizae Glomus sp. and Azotobacter chrococcum, separately and interacted, in reducing the soil content of heavy elements for the spring and fall seasons of the 2014-2015 agricultural season. It was found that the treatments of fungi and bacteria and the interaction between them were hleher by reducing the concentrations of heavy metals Zn, Cu, Fe, Mn, Mg, Co and Ni for the spring and fall seasons, with a significant increase in the vegetative growth parameters and yield of potato tubers. Potato crop (*Solanum tuberosum* L.) is one of the four most important crops in the world in terms of nutritional importance after wheat, maize, and rice, with a production of 388,191 million tons worldwide by 15.5% on an area of 19.303 million hectares (21, 41). It occupies a large place in agriculture and contains approximately 80% water, 2% protein, and 18% starch (34). The importance of potatoes is due to being the main food for many of the world's population because it contains a high percentage of carbohydrates, proteins, organic acids, vitamins, and minerals. Also, a study was conducted by (40,39) found that the water productivity of the potato crop ranged between 9.35-13.60 kg m^{-3}. This research aims to evaluate the composition of super absorbent polymers and bio-organic fertilizers in determining water consumption by reducing the quantities of added water and its role in improving the physiological performance, growth and productivity of potatoes under conditions of water deficit in desert soils.

MATERIALS AND METHODS

Two field experiments were carried out during the spring of 2020 within the Shariah area in the holy governorate of Karbala, 84 km southwest of Baghdad, at coordinates N 32° 42ˋ 13.8ˋˋ and E 43° 54 36.6ˋˋ, at an altitude of 27 m above sea level. The soil was classified as sedimentary loamy sand texture, classified to the level of *Typici Torrifluvent* according to the classification of (37). Soil samples were taken at a depth of 0-0.30 m, dried aerobically, then ground and passed through a sieve with a diameter of 2 mm. Specific physical and chemical properties of soil were determined using standard methods (Tables 1 and 2).

Table 1. Particular physical properties of field soil before planting

Property	Units	Soil Depth (0.00-0.30m)
Sand	g kg^{-1} soil	790
Silt		122
Clay		88
Soil texture		Loamy Sand
Bulk density	Mg m^{-3}	1.40
Particle density		2.65
Porosity	%	0.47
Volumetric moisture content at saturation	cm^3 cm^{-3}	0.32
Volumetric moisture content at 10 kPa		0.23
Volumetric moisture content at 1500 kPa		0.07

Table 2. Specific chemical properties of field soil before planting

Property	Units	Soil Depth (0.00-0.30 m)
Electrical conductivity $EC_{1:1}$	Ds m^{-1}	2.71
pH	---	7.64
Organic matter	g kg^{-1} soil	0.7
Carbonate minerals		300
Bicarbonate	Mmol charge L^{-1}	2.5
Calcium		23.5
Magnesium		5.4
Sodium		3.3
Potassium		2.69
Chloride		5.0
Available nitrogen	Mg kg^{-1} soil	18.21
Available potassium		72.23
Available phosphorous		8.30
Cation exchange capacity	Cmole charge kg^{-1} Soil	13.25

The experiment treatments and statistical design

1. Irrigation system:

a- Surface Drip Irrigation (T_1)

b- Sprinkler Irrigation (T_2)

2- Irrigation interval

a- Irrigation every 2 days (I_1).

b- Irrigation every 4 days (I_2).

c- Irrigation every 6 days (I_3).

3. Soil conditioners

a- Control treatment without any addition (C).

b- Bio-organic fertilizers (B).

c- Water conservation technology (polymer) (P).

d- Water conservation technology + bio-organic fertilizers (P+B).

The experiment was designed using nested design with three replicates. The main plot includes the irrigation system and within it, the irrigation intervals are distributed. The soil conditioner treatments and replicates are within the blocks. The total number of experimental units is 72 experimental units. The data were analyzed using the Gen Stat Discovery Filition 4 program (2012), and the least significant difference (LSD) at the 0.05 level was tested to compare the arithmetic means of the treatments (9). The experiment was designed on a land of 2832 m^2 area and their dimensions are 59 x 48 m, where the experimental area was divided into two sections with a distance of 4 m between to sections. Bio-fertilizers, polymers and bio-fertilizers + polymers were added together to the treatments at a rate of 1200 kg ha^{-1}, 12 kg ha^{-1} and 1200 +12 kg ha^{-1}, respectively, at a depth of 0.2 m from the soil surface. The appucation described for the treatments were SEEK bio-organic fertilizers that are granular organic fertilizers composed of charcoal, bamboo ash, lactic acid bacteria, and yeasts 100% certified organic by IMO and USDA. Coupled with Zeba polymer that is made from natural cornstarch as an inorganic compound, the molecular structure is modified to be able to store and release water. Potato tubers class (Hermosa), rank E, were planted on 10/1/2020 at a distance of 0.25 m between plant tubers, at a depth of 0.10 m. Soil was fertilized with triple superphosphate, urea, and potassium sulfate, where the tubers were uprooted on 12/5/2020. The irrigation system was calibrated at an operational pressure of 50 and 150 kPa for drip and sprinkler irrigation, respectively to achieve the best uniformity of water distribution as shown in Fig. 1 and 2.

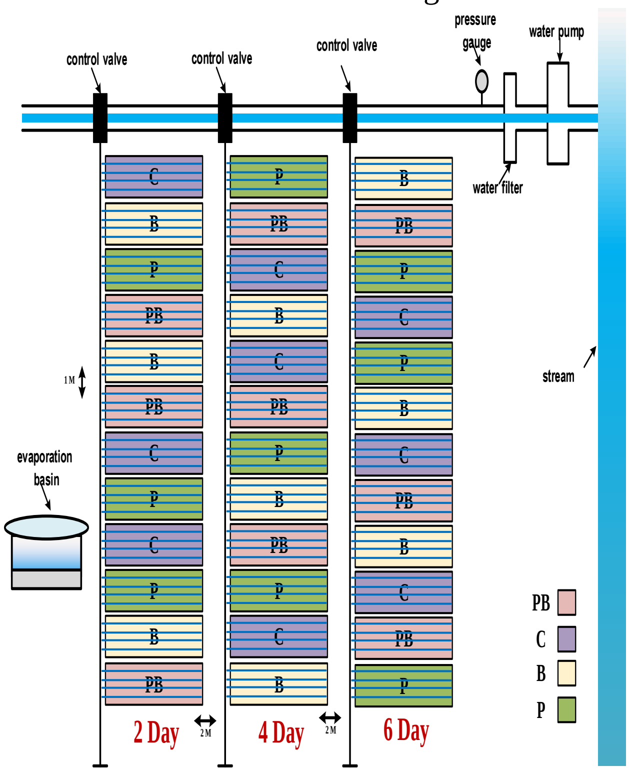

Fig. 1. Drip irrigation system diagram

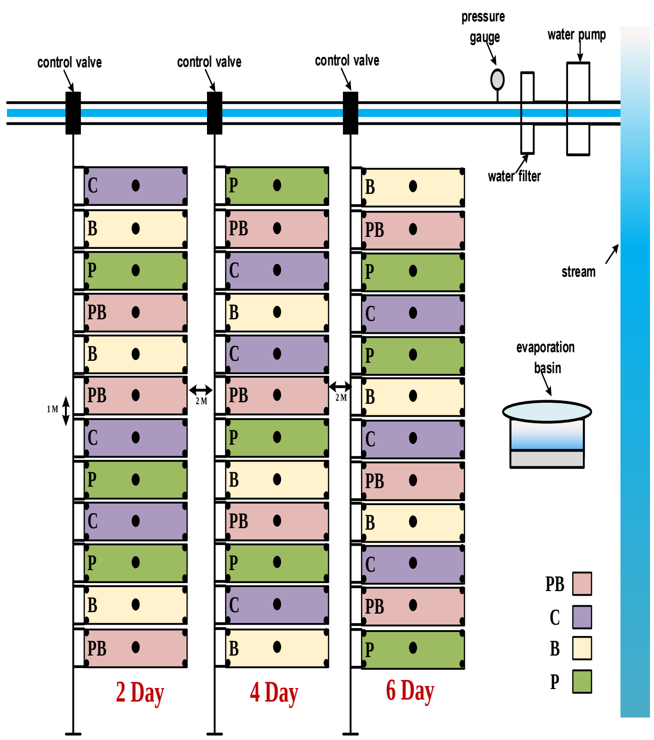

Fig. 2. Scheme of the sprinkler irrigation system

The water consumption was estimated based on the evaporation data from the American evaporation pan, class A, to calculate the amount of water to be added according to irragation intervals (2, 4 , 6) day (5) based on the evaporation data from the pan according to the equations:

$$ET_0 = K_p \times E_p \ldots\ldots.. (1)$$

and $$ET_c = ET_0 \times K_c \ldots\ldots\ldots. (2)$$

Where:

ET_0 = reference evapotranspiration (mm day^{-1}), K_p= evaporation pan coefficient 0.85 (19), E_{pan}= daily amount of evaporation from the evaporation pan (mm day^{-1}), ET_c= evapotranspiration of the crop (mm day^{-1}), and K_c = crop coefficient (0.45, 0.75, 1.15 and 0.85) by vegetative growth stage, tuber formation stage, tuber growth stage, and tuber maturity stage, respectively (20). Under the drip irrigation system, the water consumption calculated from the previous equations which modified by adding the wetness area PW according to (23).

$$Pw = \frac{S_w}{S_r} \times 100 \quad \cdots\cdots\cdots \ (3)$$

and $$ET_c = ET_o \times k_c \times Pw \quad \ldots\ldots\ldots. (4)$$

Where:

Pw = wetted area (%), Sw= minimum wetness circle diameter (m), and Sr= distance between drip lines (m). The depth of water added for each irrigation system was calculated by the equation proposed by (18). Then, the depth of water to be added and evaporated from the evaporation pan every 2, 4, and 6 days (mm) was calculated and then converted to volume units (liters) (Equ. 6).

Sprinkler irrigation

$$IWA = \frac{A \ X \ ET_c \ X \ I_i}{E_a \ X \ 1000} \ \cdots\cdots\cdots\cdots (5)$$

Where:

IWA = volume of added water (m^3), A = area of the experimental unit, ET_c = water consumption of the crop (mm day^{-1}), I_i = irrigation interval, and E_a = efficiency of the irrigation system

A- **Drip irrigation:**

The same equation above (5) was applied, where A represents the area covered by the emitter. The quantities of irrigation water for each experimental unit were calculated according to (26) equation.

$$Qt = A \times d \quad \cdots\cdots\cdots (6)$$

Where:

Q = discharge (m^3 sec^{-1}), t = irrigation time (sec), A = area of the experimental unit (m^2), and d = depth of water to be added (m). The crop coefficient for plant growth stages was calculated according to the climatic data for the year 2020 for the study area, which was obtained from the Meteorological Department/ Ministry of Agriculture, according to the modified Penman-Monteith equation of the Food and Agriculture Organization (FAO) to estimate the reference evapotranspiration ET_o (12).

RESULTS AND DISCUSSION

Field experiment applied under surface drip irrigation system

Evaluation of hydraulic parameters for surface drip irrigation system: The results of Fig. 3 show the relationship between the operating pressure and the uniformity coefficient of irrigation water distribution for the surface drip irrigation system. Thus, the relationship was inversed between them, so the uniformity coefficient decreases with the increase in the operating pressure, the highest value of the uniformity coefficient reached 94.10% at the lowest pressure of 50 kPa. Besides, when the operational pressure was increased from 50 kPa to 100 and 150 kPa, the value of the uniformity coefficient reached 93.12% and 82.04%, respectively. These results are similar with (32,4). They noted a decrease in the uniformity coefficient when the operational pressure was increased because the dripers used in the evaluation process were designed to operate under low operational pressures. Fig. 3 also shows the relationship between the uniformity of the distribution uniformity ($Du_{1/4}$) and the operational pressure. The relationship was inverse, where the ($Du_{1/4}$) decreases with an increase in the operational pressure, and the ($Du_{1/4}$) reached 90.80, 88.44, and 74.11% at operational pressures of 50, 100, and 150 kPa, respectively. The decrease in the distribution uniformity ($Du_{1/4}$) values can be attributed to the effect of drainage and operational pressure and the interaction between them. However, whenever the ($Du_{1/4}$) increased significantly, the distribution of water in the field is uniform, because the ($Du_{1/4}$) is the ratio between the discharge rate of lowest 1/4 to the total discharge rate of the dripers (33).

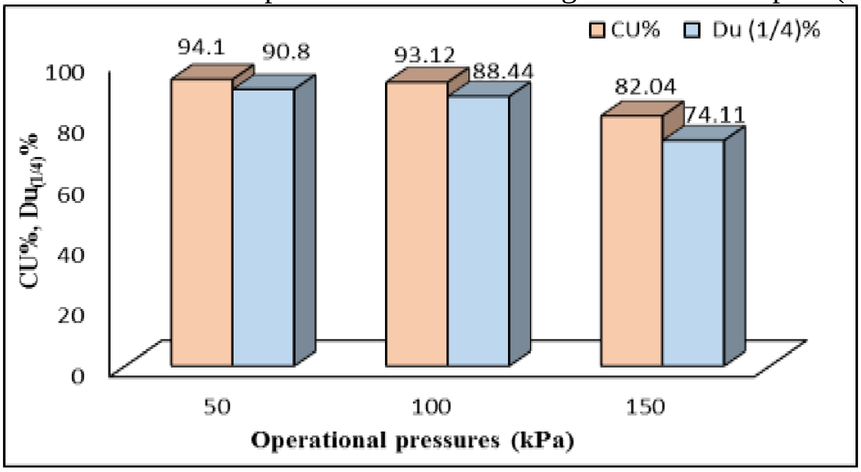

Fig. 3. Effect of different operational pressures on the uniformity coefficient (CU%) and distribution uniformity ($Du_{1/4}$%) of the surface drip irrigation system

Fig. 4 shows the variation percentage in the dripers discharge and its relationship to the operational pressure, as the results showed that the relationship is directly between them. Thus, the variation percentage increases with increasing operational pressure, and the variation percentage reached 18.54, 24.61, and 46.15% at pressures 50, 100, and 150 kPa, respectively. The difference in variation percentage values through the effect of pressures used is due to increasing the velocity of water flow inside the side drip irrigation pipes and then reduce the effect of friction between the flowing water molecules, which was the cause of increasing the variation percentage. Besides, the reason for this is that the dripers used to evaluate the system were designed primarily to work under low operational pressures (about 50 kPa or less). The actual discharge was 1.37, 2.82, and 3.09 L h^{-1} for operational pressures of 50, 100, and 150 kPa, respectively, as the flow velocity increases when the operational pressure inside the side pipe increases. Then, the friction decreases with the stability of the cross-section of the pipe (4).

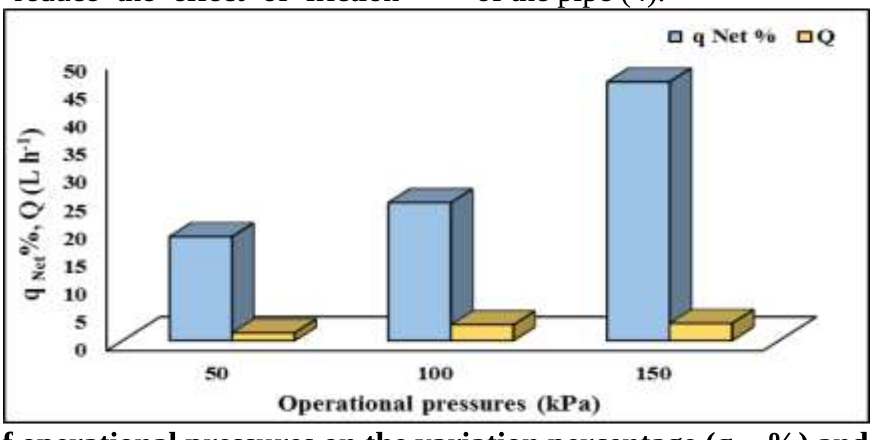

Fig. 4. Effect of operational pressures on the variation percentage (q_{Net}%) and discharge rate (Q) of the surface drip irrigation system

Water consumption during growth stages

Table 3 shows the effect of irrigation intervals I_1, I_2 and I_3 on the water consumption for each stage of the potato crop growth by the method of surface drip irrigation. Accordingly, ET_a in the germination stage, which took 34 days, was 79.50, 79.50, and 79.50 mm for the irrigation interval I_1, I_2, and I_3, respectively. Besides, the percentage of water consumption in this stage was 28.76, 18.56, and 13.41 of the total water consumption which was 276.44, 428.31, and 593.04 mm season^{-1} for the irrigation interval I_1, I_2, and I_3, respectively, this stage needed 3 irrigations. The results show that there is no difference in the amount of irrigation water depth added for the period from planting to the germination stage, with a number of irrigations equal to 3 irrigations within the irrigation intervals I_1, I_2, and I_3. Since the amount of water added in the first irrigation achieved saturation at a depth of 20 cm, while the second and third irrigations reached the field capacity at a depth of 20 cm and after 35% depletion of available water. The values of ET_a in the vegetative growth stage, tuber formation and filling stage, and tuber maturity stage reached 66.91, 103.98, and 26.05 mm of the total water consumption of 276.44 mm season^{-1}, which lasted 39, 32, and 19 days, respectively, at the 2 day irrigation interval. The percentage of water consumed in these stages was 24.20, 37.61, and 9.42% of the total water consumption, where the number of irrigations needed for these stages reached 13, 15, and 2 irrigations, respectively. However, the values of water consumption at the irrigation interval of 4 days in the vegetative growth stage, the tuber formation and filling stage, and the tuber maturity stage were 90.38, 204.41, and 54.02 mm, which lasted 39, 32, and 19 days, respectively. The percentage of water consumed in these stages was 24.20, 37.61, and 9.42% of the total water consumption, where the number of irrigations needed for these stages reached 13, 15, and 2, respectively. However, the values of water consumption at the irrigation interval of 4 days in the vegetative growth stage, the tuber formation and filling stage, and the tuber maturity stage were 90.38, 204.41, and 54.02 mm, which lasted 39, 32, and 19 days, respectively. The percentage of water consumed in these stages was 21.10, 47.72, and 12.61% of the total water consumption of 428.31 mm season^{-1}, as the number of irrigations needed for these stages reached 7, 8, and 1 irrigation, respectively. The values of ET_a in the vegetative growth stage, tuber formation and filling stage, and tuber maturity stage were 120.16, 281.44, and 111.94 mm, which lasted 39, 32, and 19 days, respectively, at the 6 day irrigation interval. The percentage of water consumed in these stages was 20.26, 47.46, and 18.88% of the total water consumption of 593.04 mm season^{-1}, where the number of irrigations needed for these stages was 5, 5, and 1 irrigation, respectively. The results showed an increase in the values of water consumption in the tuber formation and filling stage, reaching 103.98 mm for a period of 32 days by 37.61% of the total actual water consumption of 276.44 mm. This stage needed 15 irrigation due to the high temperatures with the plant growth stages, however, the water consumption decreased in the next stage at the tuber maturity stage reached 26.05 mm for a period of 19 days by 9.42% of the water consumption. It is evident from the results that the water consumption was high during the tuber formation and filling stage, and this may be attributed to the increase in evapotranspiration from the soil and plants. The transpiration through the exposed leaf surfaces was greater at this stage, the high temperature and the effect of wind caused moisture loss during the day and night hours (10, 27). The results also showed an increase in the values of water consumption in the tuber formation and filling stage for the 4 day irrigation interval, amounting to 204.41 mm by 47.72%, where this stage required 8 irrigations for a period of 32 days. Tuberous plants are characterized by their rapid growth at this stage, due to the evaporation increase from the surface of the soil due to the influence of climatic factors such as high temperatures and solar rays that supply water molecules with the energy necessary to transform the liquid into a gaseous state. In addition to winds that remove the saturated layer and replace it with a layer of dry air, as well as the fluctuation in the temperature that reflected on the potato plant (12).

Table 3. Effect of irrigation interval on water consumption of potato by surface drip irrigation system

Irrigation interval	Water consumption	Germination stage 2/12-1/10	Vegetative growth stage 13/2-22/3	Tuber formation and filling stage 4/23-3/23	Tuber maturity stage 5/12-4/24	Total
Irrigation interval (2 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	13	15	2	33
	Stage water consumption (mm)	79.50	66.91	103.98	26.05	276.44
	Water consumption ratio (%)	28.76	24.20	37.61	37.61	100
	Daily water consumption (mm)	2.34	1.72	3.25	1.37	
	Consumption rate per irrigation(mm)	26.50	5.15	6.93	13.03	
Irrigation interval (4 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	7	8	1	19
	Stage water consumption (mm)	79.50	90.38	204.41	54.02	428.31
	Water consumption ratio (%)	18.56	21.10	47.72	12.61	100
	Daily water consumption (mm)	2.34	2.32	6.39	2.84	
	Consumption rate per irrigation(mm)	26.50	12.91	25.55	54.02	
Irrigation interval (6 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	5	5	1	14
	Stage water consumption (mm)	79.50	120.16	281.44	111.94	593.04
	Water consumption ratio (%)	13.41	20.26	47.46	18.88	100
	Daily water consumption (mm)	2.34	3.08	8.80	5.89	
	Consumption rate per irrigation(mm)	26.50	24.03	56.29	111.94	

Crop coefficient

Fig. 5 shows the values of the total potato crop coefficient at the different irrigation intervals, where the crop coefficient is different according to the irrigation interval. The values of the crop coefficient were 0.59, 0.79, and 1.06 in the irrigation interval I_1, I_2, and I_3, respectively, at the vegetative growth stage of the potato crop. The crop coefficient was 0.66, 1.29, and 1.78 at the irrigation interval I_1, I_2, and I_3, respectively, at the tubers filling and forming stage. Besides, 0.20, 0.42 and 0.86 at the irrigation interval I_1, I_2, and I_3 respectively at the stage of maturity of tubers, as the highest crop coefficient was I_3, followed by I_2, and finally I_1. The increase in the crop coefficient at the stage of forming and filling the tubers is due to the increase in the nutritional and water requirements as a result of the increase in growth. This was reflected in the increase in the actual water consumption and then an increase in the crop coefficient values.

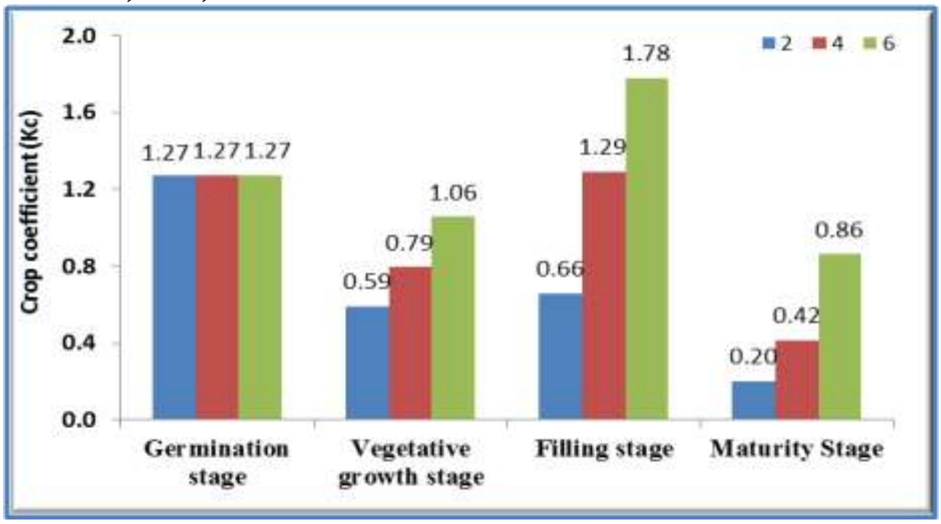

Fig. 5. Effect of irrigation intervals on crop coefficient (K_C) of potato growth stages under surface drip irrigation system

Field experiment applied under sprinkler irrigation system

Evaluation of hydraulic parameters for sprinkler irrigation system: Fig. 6 shows the relationship between CU% and $Du_{1/4}$% with the operational pressures of 50, 100, and 150 kPa for the sprinkler irrigation system. The highest percentages of %CU and %$Du_{1/4}$ at pressure 150 kPa reached 86.47 and 83.42% respectively, and at an operational pressure of

50 kPa 82.60 and 72.80%, respectively. Furthermore, when using a pressure of 100 kPa, it reached 84.55 and 77.71%. The decrease in CU% at the operational pressure of 50 and 100 kPa may be attributed to the increase in water losses such as surface run-off, deep leaching or evaporation due to the irregular distribution of spray water and the irrigated areas were heterogeneous in terms of distribution and application. However, this requires an increase in the operational pressure to increase the efficiency of distribution uniformity and application of water (30). The reason for the decrease in $Du_{1/4}$% when using the operational pressures of 50 and 100 kPa is due to the inappropriateness of the interaction ratio in the spray areas, which resulted in dry areas without water. (23) stated that the decrease in the $Du_{1/4}$ ratio of 60% is due to the poor design of the sprinkler irrigation system and the application efficiency. Along with, the $Du_{1/4}$% is low and the operational conditions are not suitable, which results in an increase in the variance of measuring the depths of water falling from sprinklers over a specific area of the experimental unit and the rate of addition in sites is lower than it is in other sites. Figure (4) also shows the relationship between the moistening depth Dm and the operational pressure, the relationship between them is direct, where the Dm increases with increasing the operating pressure with the effect of increasing the discharge, the Dm reached 4.78, 10.57, and 11.91 for the operational pressures 50, 100 and 150 kPa, respectively. Though, the discharge rates for operational pressures 50, 100, and 150 kPa were 0.75, 1.66, and 1.87 L h^{-1}, respectively.=

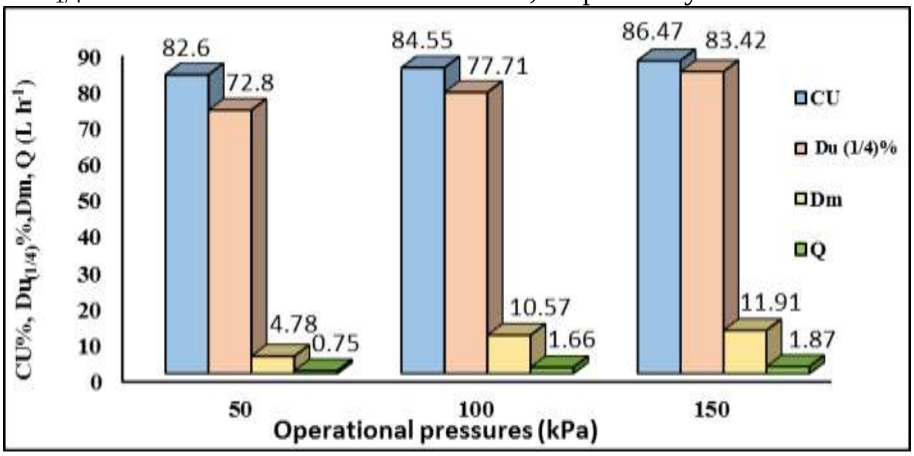

Fig. 6. Effect of different operational pressures on the (CU%), ($Du_{1/4}$%), (Dm), and (Q) of the sprinkler irrigation system

Water consumption during growth stages

Table 5 shows the effect of irrigation intervals I_1, I_2, and I_3 on the water consumption for each stage of the potato crop growth using the sprinkler irrigation method. The ET_a in the germination stage, which took 34 days, was 79.50, 79.50, and 79.50 mm for the irrigation interval I_1, I_2, and I_3, respectively. Likewise, the percentage of water consumption for this stage was 14.44, 8.29, and 5.74% of the total water consumption of 550.50, 959.46, and 1385.08 mm $season^{-1}$ for the irrigation interval I_1, I_2, and I_3, respectively. The results show that there is no difference in the depth of irrigation water added to the germination stage and the number of 3 irrigations within the irrigation intervals I_1, I_2, and I_3 because of the amount of water added to the first irrigation achieved saturation at a depth of 20 cm. Despite this, irrigations 2 and 3 reached the field capacity at a depth of 20 cm after 35% depletion of available water. The values of water consumption increased in the stage of formation and filling of tubers at the irrigation interval I_1, amounting to 294.25 mm for a period of 32 days by 53.45% of water consumption 550.50 mm. This stage needed 16 irrigation due to the high temperatures with the stages of plant growth and decreased in the maturity stage of tubers 36.85 mm for a period of 2 per day by 6.69% of the water consumption. Similarly, the results showed that the water consumption was high during the tuber formation and filling stage, and this may be attributed to the increase in evaporation and transpiration from the soil and plants. MoreoverThe transpiration through the exposed leaf surfaces was greater at this stage, the high temperature, and the influence of wind, which caused the loss of moisture during the day and night hours (12). The results also showed an increase in the water consumption values of a tuber filling and forming stage in the I_2, amounting to 542.38 mm by 56.53%, and this stage needed 8 irrigations for a period of 32 days. The small plant shoot leads to a decrease in the amount of transpiration compared to the evaporation process from the surface of the soil (12). The results showed a high consumption value in the tuber filling and forming stage, which amounted to 750.43 mm, at a rate of 54.18%, and this stage needed 5 irrigations for a period of 32 days at I_3. The reason for this is due to the development of root and shoot for the plant and this is consistent with (24). The rate of water consumption also increases when moisture is available and when the plant is not exposed to any moisture stress, as is the case of irrigation interval I_1 for the sprinkler and surface drip irrigation systems. This difference in water consumption is due to the amount of irrigation water that was added, which resulted in a difference in the number of irrigations during the growing season, which amounted to 36, 20, and 15 irrigations for irrigation intervals I_1, I_2, and I_3, respectively.

Table 5. Effect of irrigation interval on water consumption of potato by sprinkler irrigation system

Irrigation interval	Water consumption	Germination stage 2/12-1/10	Vegetative growth stage 13/2-22/3	Tuber formation and filling stage 4/23-3/23	Tuber maturity stage 5/12-4/24	Total
Irrigation interval (2 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	15	16	2	36
	Stage water consumption (mm)	79.50	139.90	294.25	36.85	550.50
	Water consumption ratio (%)	14.44	25.41	53.45	6.69	100
	Daily water consumption (mm)	2.34	3.59	9.20	1.94	
	Consumption rate per irrigation (mm)	26.50	9.33	18.39	18.43	
Irrigation interval (4 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	8	8	1	20
	Stage water consumption (mm)	79.50	260.02	542.38	77.56	959.46
	Water consumption ratio (%)	8.29	27.10	56.53	8.08	100
	Daily water consumption (mm)	2.34	6.67	16.95	4.08	
	Consumption rate per irrigation (mm)	26.50	32.50	67.80	77.56	
Irrigation interval (6 days)	Duration of the growth stage (day)	34	39	32	19	124
	Number of irrigations	3	6	5	1	15
	Stage water consumption (mm)	79.50	394.47	750.43	160.68	1385.08
	Water consumption ratio (%)	5.74	28.48	54.18	11.60	100
	Daily water consumption (mm)	2.34	10.11	23.45	8.46	
	Consumption rate per irrigation (mm)	26.50	65.75	150.09	160.68	

Crop coefficient

Fig. 7 shows the values of total crop coefficient at the different irrigation intervals, the crop coefficient differed according to the irrigation interval, which was 1.23, 2.29, and 3.47 in the irrigation interval of I_1, I_2, and I_3, respectively, at the vegetative growth stage. Furthermore, the crop coefficient was 1.86, 3.42, and 4.73 at the irrigation interval of I_1, I_2, and I_3, respectively, at the tubers filling and formation stage, and reached 0.28, 0.60, and 1.24 in the I_1, I_2, and I_3, respectively, at the maturity stage of tubers. The highest crop coefficient was at the I_3, followed by I_2, and finally the I_1. The reason for the high crop coefficient at the stage of forming and filling the tubers is attributed to the high temperatures and the high actual evapotranspiration of the crop at this stage as a result of the climatic conditions and the increase in water requirements. The crop coefficient of study treatments increased at the stage of maturity and this is due to the growth of potato plants significantly when quantities of moisture are available close to the field capacity and the plant's need for water and food to meet the requirements of this stage of the plant growth period. Therefore, the actual water consumption increases as a result of the penetration of the roots in the soil, and the area of soil volume that stores and supplies water to the roots increased, which was reflected on the crop coefficient value (7, 18, 22, 31). The crop coefficient is affected by several factors that in turn affect the state of soil moisture, such as irrigation method and frequency, climatic factors, properties of soil and crop. Also, the use of Super-absorbent polymers

(SAPs) helped to retain moisture, increase water holding capacity, and decrease the rate of infiltration in the soil, by reducing evaporation losses and retaining moisture in the effective rooting zone. In the same role, (SAPs) will feed nearby roots for a long time, and crops can better tolerate drought conditions without moisture stress through their use and reduce the frequency of irrigation (13).

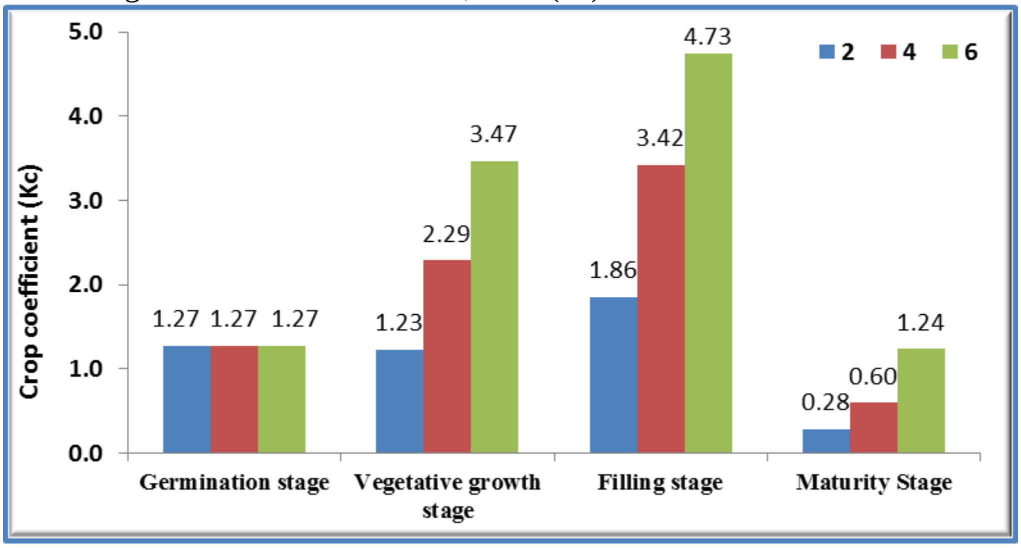

Fig. 7. Effect of irrigation intervals on crop coefficient (K_C) of potato growth stages under sprinkler irrigation system

CONCLUSION

Using a combination of bio-fertilizers and polymers when growing potatoes contributes to reducing water consumption, especially at irrigation intervals of less than 2 days, regardless of the irrigation system used. - The superiority of the surface drip irrigation system in reducing the water consumption of potatoes than the sprinkler irrigation system under the environmental conditions of desert soils under the conditions of water scarcity in those environments.

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