The Effect Irrigation Scheduling and Potassium Fertilization on Water Consumption of Potato (Solanum tuberosum L.) Under Modern Irrigation Systems

A S Ati, H A Razin*

College of Agriculture Engineering Sciences, University of Baghdad, Baghdad, Iraq

*Corresponding author's e-mail: hawraa.abdalwahid1207a@coagri.uobaghdad.edu.iq

Abstract. A field experiment was conducted in Yusufiya sub-district - Mahmudiya township/Baghdad governorate in silty loam texture soil during the spring season of 2020. The experiment included three treatments with three replicates, as the Randomized Complete Block Design (RCBD) was used according to the arrangement of the split design block. The treatments are in the irrigation system, which included surface drip irrigation (T1) and sprinkler irrigation (T2). Secondly, the Irrigation levels including the irrigation using 0.70 Pan Evaporation Fraction PEF (I1), irrigation using 1.00 PEF (I2), and irrigation using 1.30 PEF (I3). Coupled with, Potassium fertilization treatments that include 0.0 kg k ha⁻¹ (K1), 150 kg k ha⁻¹ (K2), and 300 kg k ha⁻¹ (K3)). The results showed that the actual seasonal water consumption reached its peak at irrigation level I1, which reached 390.03 and 256.41 mm for the sprinkler and drip irrigation systems, respectively. However, the actual seasonal water consumption at irrigation level I2 was 373.92 and 255.63, and it was 353.82 and T255.15 mm at irrigation level I3 for the sprinkler and drip irrigation systems, respectively. The lowest values of the crop coefficient at the tuber maturity stage using the sprinkler irrigation system were 0.49, 0.46, and 0.44, and at the vegetative growth stage using the surface drip irrigation system by 0.37, 0.32, and 0.38 for irrigation levels I1, I2, and I3 levels, respectively. Even though the greatest values were in the tuber Initiation and bulking stages as they reached 0.86, 0.66, and 0.79 using the sprinkler irrigation system, while they reached 0.49, 0.54, and 0.51 using the surface drip irrigation system for I1, I2, and I3 levels, respectively. The highest water productivity for treatment I1K3 was 15.70 and 27.20 kg m⁻³ of sprinkler and surface drip irrigation systems, respectively. In contrast, the lowest water productivity was 8.73 and 17.72 kg m⁻³ for treatment I1K1 of sprinkler and surface drip irrigation systems, respectively. Whereas, the highest value of crop water use efficiency was 11.70 and 17.58 kg m⁻³ for I1K3 treatment of sprinkler and surface drip irrigation systems, respectively. Although, the lowest value of crop water use efficiency was 6.71 and 11.49 kg m⁻³ for I1K1 treatment of sprinkler and surface drip irrigation systems, respectively. Lastly, the highest yield was 44.87 Mg ha⁻¹ at treatment T1I1K3.
1. Introduction

Agriculture is an essential element for economic development and food security in emerging countries, as it provides a source of income for three-quarters of the world's poor. However, food production requires large amounts of water, since water resources are under pressure in several parts of the world due to meet energy needs, and due to the increase in population. Studies expect a decrease in the available water resources due to climatic changes, where the area available for agriculture continues to decrease as a result of urbanization and agricultural degradation [1]. The Tigris and Euphrates river's flow rates have decreased significantly in recent years due to the lack of rainfall, and as a result, water revenue has decreased [2]. Therefore, proper irrigation scheduling is the most important factor for crop growth, which is necessary to rationalize water use and depends on the soil, crop, and atmospheric systems. The appropriate irrigation frequency can achieve good moisture conditions and oxygen content in the root zone throughout the growing season [3]. Reality necessitates take practical measures to rationalize and raise the value of the invested water unit by increasing its productivity to achieve balanced agricultural development with population growth and the increasing demand for food. Thus, the use of sprinkler and drip irrigation systems as an alternative to traditional irrigation methods in irrigation and water management is an essential way to rationalize water, reduce water losses, and improving the performance efficiency of field irrigation systems. These systems have proven successful in arid and semi-arid areas, as modern irrigation systems provide a high possibility of controlling water and achieving high uniformity, which increase the productivity of crops and the productivity of water units [4]. Potato \((Solanum tuberosum\) L.) is one of the most important vegetable crops worldwide and is the fourth most important food crop in the world after wheat, corn, and rice, with a production of 388 million tons in 2017. It belongs to the Solanaceae family, its native is the Andes mountain range [5].

The current study aims to investigate the effect of irrigation scheduling and potassium fertilization levels on water consumption and water productivity of the potato crop and calculate the values of the crop coefficient \(K_c\) according to the plant growth stages.

2. Materials and Methods

A field experiment was carried out on soil with a silty loam texture during the spring season of 2020, in Baghdad Governorate / Mahmudiya District - Yusufiya township. The soil was morphologically described and classified to the level of Typic Torrifluvent according to the classification of Soil Survey Staff [6]. Representative samples of field soil were taken from different regions and randomly at a depth of 0.0 to 0.30 m. Soil samples were dried aerobically, then crushed and passed through a sieve with 2 mm holes, as specific physical and chemical analyzes of the soil were carried out as shown in Table 1. The water of Yusufiya River with electrical conductivity (EC) 0.8 dS m\(^{-1}\) and pH of 7.06 classified as C\(_1\)S\(_1\) was used for irrigating the potato crop. The experiment included a study of three treatments and three replications, where the RCBD was used according to the arrangement of the Split Design Block. The experimental study treatments were the irrigation system that includes surface drip irrigation (T\(_1\)) and Sprinkler irrigation (T\(_2\)) Secondly, Irrigation levels, which including irrigation with PEF 0.70 (I\(_1\)), irrigation with 1.00 PEF (I\(_2\)), and irrigation with PEF 1.30 (I\(_3\)). Besides, Potassium fertilization, that including 0.0 kg k ha\(^{-1}\) (K\(_1\)), 150 kg k ha\(^{-1}\) (K\(_2\)) and 300 kg k ha\(^{-1}\) (K\(_3\)). The data of the results were analyzed using the (Genstat, v12.1) model, and the means were compared with the least significant difference test (LSD).
Table 1. Some physical and chemical properties of field soil before planting

| Property                  | Unit         | Soil depth (0.00-0.30m) |
|---------------------------|--------------|-------------------------|
| Sand                      | g kg\(^{-1}\) soil | 220                     |
| Silt                      | g kg\(^{-1}\) soil | 552                     |
| Clay                      | g kg\(^{-1}\) soil | 228                     |
| Soil texture              |              | Silty loam              |
| Bulk density              | Mg m\(^{-3}\) | 1.32                    |
| Particle density          |              | 2.65                    |
| Porosity                  | %            | 50.19                   |
| The volumetric moisture content at 33 kPa |         | 0.381                   |
| The volumetric moisture content at 1500 kPa | Cm\(^{3}\) cm\(^{-3}\) | 0.212                   |
| Available water           |              |                         |
| Electrical conductivity 1:1EC | dS m\(^{-1}\) | 2.28                    |
| pH                        |              | 7.29                    |
| Organic matter            | g kg\(^{-1}\) soil | 8.25                    |
| Carbonate minerals        | g kg\(^{-1}\) soil | 230                     |
| Available Nitrogen        |              | 28.22                   |
| Available phosphorous     | Mg kg\(^{-1}\) soil | 8.33                    |
| Available Potassium       |              | 123                     |

The experiment was conducted on a land of 1452 m\(^{2}\) with a dimension of 66m x 22m, where the land was plowed with a moldboard plow, in an orthogonal plow, harrowing operations were carried out using the rotary cultivator, as the area of one experiment was (704 m\(^{2}\)) and the distance between the two systems was (2 m\(^{2}\)). The field for each system was divided into 3 main blocks representing irrigation levels, as the distance between one block and another was (2 m). These blocks were divided into 9 experimental units, where the area of one experimental unit (3 m x 6 m = 18 m\(^{2}\)), while the distance between the experimental units (0.5 m) and the distance between one replicate and another (1 m). Each experimental unit contains 6 beds, the length of a bed (3 m), width (0.60 m), height (0.25 m), and the distance between one bed and another (0.40 m). Irrigation was carried out through an earthen basin that was specially constructed for the experiment, its dimensions are 12 m x 4 m x 3 m, as the basin was lined with polyethylene to prevent water from leaking into the bottom, where the irrigation water is pumped from the basin by a gasoline-powered water pump. The sprinkler irrigation system consists of a pumping unit, which includes a water pump of a discharge of 12 m\(^{3}\) per hour and a filter. Secondly, the pipe unit includes a water drainage pipe with a diameter of 3 in, main tubes with a diameter of 1.5 in. Besides, secondary tubes with a diameter of 1.5 in, which are three tubes, and sub tubes with a diameter of 16 mm, 3 tubes for each experimental unit. Coupled with, the sprinkler unit, which includes the mist sprayers, where the spray angles were of two types (90 and 360 XS). Similarly, the surface drip irrigation system consisted of the pumping unit with a discharge of 12 m\(^{3}\) per hour and a filter and without blocking the drippers. Secondly, the pipe unit, which includes a water drainage pipe with a diameter of 3 in, the main pipe with a diameter of 1.5 in and. Besides, the secondary tubes with a diameter of 1.5in, which are three tubes and sub tubes s (drip tubes) type T-Tap with a diameter of 16 mm, 6 tubes in each experimental unit, the distance between one dotted and
another is 0.1 m, and the number of drippers for the experimental unit is 180 drippers. Combined with fittings that including a water drain meter, pressure gauges, and water control valves. Potato seeds of Hermosa Var. rank E were planted on 7/1/2020 at a depth of 0.10 m, at a rate of 72 tubers per experimental unit, where the distance between one tuber and another was 0.25 m. So that, the number of tubers for one experiment was 1944 and 3888 tubers for the two experiments. The experiment land was fertilized with triple superphosphate fertilizer at planting (20% P) according to the recommendation for fertilizer 100 kg P ha\(^{-1}\) at planting. Moreover, Urea fertilizer (46% N) was added according to the fertilizer recommendation 300 kg N ha\(^{-1}\) in three batches, the first after 20 days of planting, the second after 30 days of the first batch, the third after 25 days of the second batch according to the fertilizer recommendation 300 kg N ha\(^{-1}\) [7]. Potassium sulfate fertilizer was added in three batches, the first after 20 days of emergence, the second after 25 days from the first batch, the third after 30 days from the second batch, according to the fertilizer potassium treatments 0,150, and 300 kg K ha\(^{-1}\) by making a groove 0.1 m away from the planting row with a depth of 0.1 m. The plants were controlled from blight by using a pesticide (Ramadin) each 1 kg containing 200 g (Copper Sulfate) and 16 g (Cymoxanil). The process of manual weeding for the field was carried out using manual machines whenever necessary. Potato tubers were removed manually on 10/5/2018. The surface drip and sprinkler irrigation systems were evaluated using several criteria, as the distribution uniformity coefficient of the surface drip and sprinkler irrigation systems was studied through the following (equation 1) [8]:

\[
U_c = \left(1 - \frac{\sum{|x_i|}}{Mn}\right) \times 100 \ldots \ldots (1)
\]

Since:
- \(U_c\) = uniformity coefficient (%).
- \(\sum{|x_i|}\) = sum of deviations from discharge rate (liter hour\(^{-1}\)).
- \(M\) = average discharge of emitters or sprinklers (liter hour\(^{-1}\)).
- \(n\) = number of emitters or sprinklers.

The distribution uniformity for the least quarter was calculated to assess the losses of deep infiltration and the economic efficiency of surface drip irrigation and sprinkler systems using equation (2) mentioned by [9].

\[
Du(1/4) = \frac{D_{iq}}{Dac} \ldots \ldots (2)
\]

Since:
- \(Du(1/4)\) = distribution uniformity for the least quartile (%).
- \(D_{iq}\) = average depth of water for the least quarter (mm).
- \(Dac\) = average total water depths (mm).

The Application Efficiency was calculated for surface drip irrigation using equation (3) mentioned in [10]:

\[
E_a = \frac{v(1 - Dd)}{3600 \times Q_t \times T_a} \ldots \ldots (3)
\]

Since:
- \(E_a\) = Application efficiency (%).
- \(V\) = volume of water required for irrigation at the root depth (liters).
- \(Dd\) = Theoretical allowable decrease of moisture in the soil.
- \(Q_t\) = Drip tape discharge (liters sec\(^{-1}\)).
• \( Ta \) = total irrigation time (hours).

Then, the Application efficiency of the sprinkler irrigation method was calculated through equation (4) which was mentioned by [11].

\[
\text{irrigation efficiency} = \frac{\text{Useful water}}{\text{Total given water}} \times 100 \quad \ldots(4)
\]

The variance percentage in the discharge along the lateral line of the surface drip irrigation system was calculated according to [12]; [13] Equation (5):

\[
q_{\text{var.}} = \frac{q_{\text{max}} - q_{\text{min.}}}{q_{\text{max.}}} \times 100 \quad \ldots(5)
\]

Where:-
• \( q_{\text{var.}} \) = Emitter discharge variance (liter hour\(^{-1}\)).
• \( q_{\text{max}} \) = maximum emitter discharge (liter hour\(^{-1}\)).
• \( q_{\text{min.}} \) = minimum emitter discharge (liter hour\(^{-1}\)).

Application Adequacy (Ad) was calculated for the sprinkler irrigation system, which represents the ratio of the field area in which the depth of water entering the soil is equal to or greater than the net irrigation depth, it is calculated through equation (6) that mentioned by [11] as follows:

\[
\text{Application Adequacy} = \frac{\text{number of data equal to or greater than the net irrigation depth}}{\text{total number of data}} \times 100 \quad \ldots(6)
\]

A water depth of 35.4 mm was added to the first irrigation \((\theta_w = 0.263)\) to achieve a water balance within the root zone of a depth of 30 cm and 17.4 mm to the second irrigation \((\theta_w = 0.212)\) and to all treatments for germination based on (Equation 7) which was mentioned in [14]

\[
d = (\theta_{fc} - \theta_w) \times D \quad \ldots(7)
\]

Since:
• \( d \) = depth of water added (mm).
• \( \theta_{fc} \) = volumetric moisture at field capacity (cm\(^3\)cm\(^{-3}\)).
• \( \theta_w \) = volumetric moisture before irrigation (cm\(^3\)cm\(^{-3}\)).
• \( D \) = soil depth which is equal to the effective root depth (mm).

The water depths to be added and the irrigation interval was calculated based on the available water and in terms of Maximum Allowable Depletion MAD, which is 35% for the potato crop to a depth of 30 cm. The irrigation scheduling was started according to the experimental treatments after the completion of seedling emergence, as of 10/2/2020, until 30/4/2020. Equation (8) mentioned in [15] was adopted in calculating the value of the CPE:

\[
E_F = \frac{\text{IW}}{\text{CPE}} \quad \ldots(8)
\]

Since:
• \( E_F \) = irrigation treatments,
• \( \text{IW} \): actual depth of available water (50.7 mm) multiplied by the depletion percentage
• \( \text{CPE} \). The irrigation interval was calculated based on (Equation 9):
Since:

- $\text{evaporation from the evaporation pan (mm day}^{-1}\text{)}$ and calculated through (Equation 4),
- $K_p = \text{evaporation pan coefficient of 0.85 [16].}$

The amount of water added (equivalent depth) was calculated in terms of (Equation 11) mentioned according to [16].

$$IW = \frac{CPE \times K_c \times K_p \times K_r}{E_a} \ldots \ldots (11)$$

Since:

- $K_c$: Crop coefficient (0.75, 1.15, and 0.85) for the stage of vegetative growth, Initiation and bulking stages of tubers and tuber maturity, respectively.
- $K_p$: evaporation pan coefficient (0.85).
- $K_r$: reduction coefficient (when applying the drip irrigation system) (0.41, 0.53, and 0.92) for the stage of vegetative growth, Initiation and bulking of tubers and tuber maturity, respectively according to (Equation 12) mentioned in [17],
- $E_a$: Application efficiency (0.91% for surface drip irrigation system, 0.82% for sprinkler irrigation system) from Equation 3, 4.

$$Kr = \frac{Ge}{0.85} \ldots \ldots (12)$$

Since:

- Ge: The ratio of what is covered from the soil surface to the total area of the experiment.

The crop coefficient was calculated for the stages of plant growth, according to the climatic data of the study area, the data on the meteorological conditions were obtained from the Meteorological Department of the Ministry of Agriculture according to (Equation 13)

$$K_c = \frac{ET_c}{ET_0} \ldots \ldots (13)$$

Water Productivity was calculated according to equation 14 according to the equation mentioned in [14]

$$Wp = \frac{\text{yield}}{\text{water applied}} \ldots \ldots (14)$$

Since: -

- $Wp = \text{water Productivity (kg m}^{-3}\text{).}$
- Yield = total yield (kg ha$^{-1}$) and water applied = added water (m$^3$ ha$^{-1}$).

Crop Water Use Efficiency was calculated according to equation 15 mentioned in [14]
Since:

- \( WUE_c = \frac{\text{yield}}{\text{ET}_a} \) ...

\[ (15) \]

Growth and yield traits were measured by selecting ten plants randomly from each experimental unit for each replicate, which included plant height, shoot dry weight, leaf area, number of aerial stems, and total yield weight.

3. Results and Discussion

3.1. Sprinkler irrigation system

3.1.1. Evaluation of the hydraulic parameters of the sprinkler irrigation system. Figure (1) shows the relationship between the uniformity coefficient \( CU\% \), Application adequacy \( AD\% \), and irrigation application efficiency \( Ea\% \) with the operating pressure of 50, 100, and 150 kPa for the small sprinkler irrigation system. The highest values at a pressure of 100 kPa reached 84.80, 75.00, and 81.74\% for \( CU \), \( AD \), and \( Ea \), respectively. However, at the operating pressure of 50 kPa, they reached 70.20, 70.00, and 80.46\%, respectively, while they were 77.57, 70.00, and 70.67\%, respectively using pressure 150 kPa. The low efficiencies percentages (\( CU \), \( AD \), and \( Ea \)) at the operating pressure of 50 kPa are attributed to the increase in water losses as surface run-off, deep leaching, or evaporation due to the irregular distribution of spray water on the experimental unit, and also the irrigated areas were heterogeneous in terms of distribution and addition of spray water. On the other hand, a decrease in (\( CU \), \( AD \), and \( Ea \)) at the operating pressure of 150 kPa may be attributed to the increase in the water diameter from the sprinkler due to the increase in pressure that led to the spraying water falling outside the experimental unit. Otherwise, the dispersion of water during spraying, causing irregular water distribution on the experimental unit, which causes the low efficiency of uniformity coefficient. The design of sprinkler irrigation systems is not acceptable if the efficiency of uniformity and application efficiency is less than 75\% [18].

Figure (1) shows the relationship between the efficiency of \( Du_{1/4} \) and operation pressures, where the highest \( Du_{1/4} \) recorded using the operating pressure of 100 kPa by 78.43\%, while the operating pressures of 50 and 150 kPa gave lower values that were 45.30 and 60.82\%, respectively. This may be due to the inappropriateness of the interaction ratio in the spray areas, which generated arid areas that the spray water did not reach. [19] stated that the decrease in the \( Du_{1/4} \) ratio of 60\% is referred to as a poor design of the sprinkler irrigation system. Besides that, the Application Efficiency and uniformity of distribution for the least quarter are low and the operating conditions are not suitable, which increases the variance of measuring the depths of water falling from the sprinklers over a specific area from the experimental unit and the rate of addition in sites is lower than in other sites of the experimental unit. In light of the results obtained from evaluating the sprinkler irrigation system, the best operation pressure gave the highest values of uniformity coefficient, application adequacy, application efficiency, and distribution uniformity \( Du_{1/4} \) is 100 kPa.
3.1.2. Water consumption. Table 2 shows that there is no difference in the amount of irrigation water added for the period from planting until the end of the 34-day germination stage, with 2 irrigations (the amount of water added in the first and second irrigations was equal) within both the irrigation levels I₁, I₂, and I₃ and the treatment of one irrigation system. Moreover, the depth of added water in the germination stage was 52.8 mm for all irrigation levels, because the amount of water added in the first irrigation was reached to the field capacity with a depth of 30 cm, while the second irrigation was reached to the field capacity with a depth of 30 cm and after depletion 35% of the available water and for all irrigation level treatments. The depth of rainfall at the germination stage was 40.2 mm, which is sufficient to give the third irrigation at that stage, in addition to the fact that the temperatures and wind speeds were at their lowest rates. Irrigation levels were separated and applied during the beginning of the vegetative growth stage on 10/2/2020, where the highest water consumption was in the 33 and 23 days of tuber Initiation and bulking and tuber maturity stages, respectively. Figure (2) shows the amount of rainfall during the growth stages of the potato crop since the stage of tuber Initiation and bulking and maturity represents the stage of increasing the growth and plant size with rapid rates of development to complete physiological growth. Thus, the plant’s need for water consumption increased significantly, which was reflected in the rates of evapotranspiration in these two stages as a result of the increase in root depth and its spread. Then, increasing its efficiency in absorbing water and increasing the surface area of leaves, which increased the water lost from the plant through transpiration to reach its highest rate for all treatments. The plant is fully grown within high temperatures, which indicates an increase in water losses during those months, and then an increase in the water needs of the crop. Also, the rate of evapotranspiration of potato crops increases with increasing the plant age, as water consumption reaches its maximum depth in March and April. The influence of climatic factors increases in these months, such as temperatures and wind speed, and then leads to an increase in the values of depth for irrigation water added during these stages. Even though, the quantities of water consumption started decreasing in the tuber maturity stage and for all levels of irrigation that coincides with the completion of the Initiation and bulking of tuber and start the 23-day maturity stage, high temperatures, low saturated steam pressure, and increased wind speed.
The total depth of water added during the growing season was 299.83, 283.72, and 263.62 mm, with several added irrigations 12, 15, and 18 for irrigation levels I₁, I₂, and I₃, respectively, using the micro-spray irrigation system. The decrease percentage in the depth of water added in the treatment IW: CPE were 0.1 and 1.3 was 5.37% and 12.08% compared to the 0.7 IW: CPE treatment, as the actual seasonal water consumption, reached its peak at I₁ level of 390.03 mm. However, the actual seasonal water consumption at irrigation level I₂ was 373.92 and at irrigation level I₃ it was 353.82 mm.

Table 2. Depths of the added irrigation water according to growth stages and total depth (mm) according to irrigation treatments using the sprinkler irrigation system

| Rain water depth | During the growing season | Tuber maturity stage (18/4-10/5) | Tuber initiation and bulking stage (16/3-17/4) | Vegetative growth stage (10/2-15/3) | Germination stage (7/1-9/2) | Number of irrigations during the season | Irrigation levels PEF |
|------------------|---------------------------|----------------------------------|---------------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------------|----------------------|
| 390.03           | 90.2                      | 299.83                           | 67.02                                       | 12.08                             | 59.13                             | 52.8                                    | 12                   |
| 373.92           | 90.2                      | 283.72                           | 62.56                                       | 126.96                            | 41.40                             | 52.8                                    | 15                   |
| 353.82           | 90.2                      | 263.62                           | 60.15                                       | 97.62                             | 53.05                             | 52.8                                    | 18                   |

3.1.3. Crop coefficient Kc. Figure 3 shows the values of the crop coefficient at each stage of potato growth and for irrigation levels when using the sprinkler irrigation system. It can be observed that the value of the crop coefficient of 1.61 is equal in the germination stage and for all the irrigation levels due to the use of a surface irrigation system in this stage. Accordingly, the value of the actual water consumption was equal, and that the lowest values of the crop coefficient were at the stage of tuber maturity, which amounted to 0.49, 0.46, and 0.44 for the irrigation levels I₁ and I₂ and I₃, respectively. However, the greatest values were in the tuber formation and filling stage, which were 0.86, 0.66, and 0.79 for irrigation levels I₁, I₂, and I₃, respectively. This coefficient varies according to the different growth stages of the crop and the climatic conditions, it is also affected by the factors that affect the
plant density and the coverage ratio of the earth’s surface, which is affected by the leaf area, the part of the land covered by vegetation cover, leaves age, opening and closing of the stomata, and moisture of the soil surface.

Figure 3. Crop coefficient Kc of potato growth stages for irrigation treatments for the spring season 2020 under sprinkler irrigation system.

3.1.4. Water productivity

3.1.4.1. Water productivity. The results in Figure 4 show the effect of irrigation level and potassium fertilization on the efficiency of field water use (kg m$^{-3}$) using the sprinkler irrigation system, as the efficiency of field water use varies with different levels of irrigation. The statistical analysis shows that there are significant differences, where the highest efficiency of field water use reached 15.70 kg m$^{-3}$ for I$_3$K$_3$ treatment. The increasing percentage for I$_3$K$_3$ treatment was 79.84, 58.59, 35.58, 56.37, 37.36, 18.31, 28.90 and 10.88% for I$_1$K$_1$, I$_1$K$_2$, I$_1$K$_3$, I$_2$K$_1$, I$_2$K$_2$, I$_3$K$_3$, I$_1$K$_1$, and I$_3$K$_2$ treatments, respectively, while the lowest value was 8.73 kg m$^{-3}$ for I$_1$K$_1$ treatment. The decrease in the values of water productivity of the sprinkler irrigation system and its increase using the drip irrigation system is attributed to the increase in the depths of water added when using the sprinkler irrigation system in addition to the decrease in the biological yield. Alternatively, the low water productivity for irrigation level I$_1$ is attributed to the use of fewer irrigations with a converging water depth compared to irrigation level I$_3$, which led to washing the nutrients below the root zone. Along with, a decrease in their concentrations and then a decrease in productivity, which in turn leads to a decrease in the efficiency of water use [20].
3.1.4.2. Crop water use efficiency. Figure 5 shows significant differences in the interaction of the effect of irrigation level and potassium fertilization on the crop water use efficiency (kg m\(^{-3}\)) using the sprinkler irrigation system. The lowest crop water use efficiency was 6.71 kg m\(^{-3}\) in the I\(_1\)K\(_1\) treatment, while the highest crop water use efficiency in the I\(_3\)K\(_3\) treatment was 11.70 kg m\(^{-3}\) with an increase of 74.37, 53.75, 31.46, 53.54, 34.95, 16.19, 28.85 and 10.90% for the treatments I\(_1\)K\(_1\), I\(_1\)K\(_2\), I\(_1\)K\(_3\), I\(_2\)K\(_1\), I\(_2\)K\(_2\), I\(_2\)K\(_3\), I\(_3\)K\(_1\), and I\(_3\)K\(_2\), respectively.

3.2. Surface drip irrigation system

3.2.1. Evaluation of the hydraulic parameters of the surface drip irrigation system. The results of Figure (6) show the relationship between the operating pressure and the uniformity coefficient of irrigation water distribution for the surface drip irrigation system, as the relationship was inverse between them, where the uniformity coefficient decreases with increasing the operating pressure. The highest value of the uniformity coefficient reached 94.43% at the lowest pressure of 50 kPa and the pressures of 100 and 150 kPa were 90.89% and 87.70%, respectively. These results are consistent with [21]; [22] findings, where they observed a decrease in the uniformity coefficient when the operating
pressure was increased. The reason is that the emitters used in the evaluation process were designed to operate at low operating pressures and that high pressures cause the irregular flow of water distribution. The distribution uniformity $Du_{1/4}$ was 91.70, 81.78, and 79.29% at operating pressures of 50, 100, and 150 kPa, respectively. The decrease in $Du_{1/4}$ values can be attributed to the effect of discharge and operating pressure and the interaction between them. But, with the increase in the values of $Du_{1/4}$ significantly, the water distribution in the field is uniform, because the distribution uniformity $Du_{1/4}$ is a ratio between the discharge rate of the least quarter to the total discharge rate for the emitters [23]. The application efficiency of irrigation was 91.27, 46.14, and 40.27% for the operating pressures of 50, 100, and 150 kPa, respectively. Since the increase in the actual discharge rate by increasing the operating pressure leads to a decrease in the irrigation application efficiency because the application efficiency has an inverse relationship with the actual discharge rate.

![Figure 6. Effect of different operating pressures on the (CU), (q var), (Du 1/4), and (Ea) for the surface drip irrigation system](image)

The variance percentage $q_{var}$ increases with increasing operation pressure, as the variance percentage reached 17.57, 42.62, and 46.66% at pressures 50, 100, and 150 kPa, respectively. The difference in the values of the varying percentage through the effect of the pressures used is due to the increase in the velocity of the water flow in the side drip pipes and then reducing the effect of friction between the flowing water molecules, which was the cause of the increase in values of $q_{var}$ [24]. In light of the results obtained at evaluating the surface drip irrigation system, the best operation pressure was 50 kPa, which gave the highest values of CU% and $Du_{1/4}$, Ea% and the lowest $q_{var}$.

### 3.2.2. Water consumption

(Table 3) shows the depth of water used during potato growth stages according to irrigation levels 0.7, 1.0, and 1.3 IW:CPE uses the surface drip irrigation system. The depth of water added during the germination stage was equal for all irrigation treatments because the system used in the germination stage is the surface irrigation system. Besides that, the minimum depth of water added was in the vegetative growth stage, which reached 14.56, 10.20, and 15.68 mm for irrigation levels I$_1$, I$_2$, and I$_3$, respectively. The highest water depth added to the tuber maturity stage was 55.56, 51.88, and 49.85 mm for irrigation levels I$_1$, I$_2$, and I$_3$, respectively. The total depth of water added to the surface drip irrigation system was 166.21, 165.43, and 164.95 mm, with 10, 13, and 17 irrigations added during the season for irrigation levels I$_1$, I$_2$, and I$_3$, respectively. The actual seasonal water consumption reached its peak at irrigation level I$_1$, reaching 256.41 mm, while it was 255.63 and 255.15 mm at the irrigation level I$_2$ and I$_3$, respectively. The reason for the low water requirements using the surface drip irrigation system maybe because the water is added directly to the
soil surface and the effective root area, thus reducing evaporation from the soil surface and the absence of losses of spray and deep leaching.

Table 3. Depths of the added irrigation water according to growth stages and total depth (mm) according to irrigation treatments using the surface drip irrigation system

| Actual water consumption | Rain water depth | Added water depth (mm) | Number of irrigations during the season | irrigation levels PEF |
|--------------------------|-----------------|------------------------|----------------------------------------|----------------------|
|                          |                 | During the growing season | Tuber maturity stage (18/4-10/5) | Tuber Initiation and bulking stage (16/3-17/4) | Vegetative growth stage (10/2-15/3) | Germination stage (7/1-9/2) |                           |                           |
|                          |                 |                        | 55.56 | 43.29 | 14.56 | 52.8 | 10 | 0.7 | IW:CPE |
| 256.41                   | 90.2            | 166.21                 | 55.56 | 43.29 | 14.56 | 52.8 | 10 | 0.7 | IW:CPE |
| 255.63                   | 90.2            | 165.43                 | 51.88 | 50.55 | 10.20 | 52.8 | 13 | 1.0 | IW:CPE |
| 255.15                   | 90.2            | 164.95                 | 49.85 | 46.62 | 15.68 | 52.8 | 17 | 1.3 | IW:CPE |

The coverage provided by the vegetative part of the plant is an important factor in maintaining the water balance of the soil surface by reducing evaporation from the soil surface. Besides, the increase in vegetative growth resulted in a clear shading below the area surrounding the plant and reduces the area exposed to evaporation from the soil surface. The difference in the depth of added water with the increase in the value of $E_{\text{pan}}$ is due to the values of $K_r$, which contributed to the decrease in the values of IW. Coupled with rising temperatures, decreasing saturated vapor pressure, and increasing wind speed.

3.2.3. Crop coefficient $K_c$. Figure (7) shows the crop coefficient values for each stage of potato growth and irrigation levels when using the surface drip irrigation system. It can be observed that the value of the crop coefficient of 1.61 is equal in the germination stage and for all levels of irrigation due to the use of a surface irrigation system at this stage. Thus, the value of actual water consumption was equal, and the lowest values of the crop coefficient at the vegetative growth stage reached 0.37, 0.32, and 0.38 for irrigation levels $I_1$, $I_2$, and $I_3$ respectively. However, the greatest values were in the tuber Initiation and bulking stages, which were 0.49, 0.54, and 0.51 for irrigation levels $I_1$, $I_2$, and $I_3$, respectively. Then, the values of crop coefficient decreased at the tuber maturity stage, reaching 0.41, 0.38, and 0.37 due to the low values of actual water consumption for this stage than the tuber Initiation and bulking stages.

![Crop coefficient Kc for potato growth stages of irrigation treatments for the spring season 2020 under the surface drip irrigation system](image-url)
3.2.4. Water productivity

3.2.4.1. Water productivity. The results of Figure 8 showed the effect of irrigation level and potassium fertilization on the water productivity (kg m\(^{-3}\)) using the surface drip irrigation system. The statistical analysis shows that there are significant differences, as the highest water productivity reached 27.20 kg m\(^{-3}\) for the I\(_1\)K\(_3\) treatment, with a significant increase of 53.50, 35.53, 26.57, 36.89, 22.30, 15.01, 18.83, and 10.17% for the treatments I\(_1\)K\(_1\), I\(_1\)K\(_2\), I\(_2\)K\(_1\), I\(_2\)K\(_2\), I\(_2\)K\(_3\), I\(_3\)K\(_1\), and I\(_3\)K\(_2\), respectively. In contrast, the lowest water productivity was 17.72 kg m\(^{-3}\) for I\(_1\)K\(_1\) treatment using the surface drip irrigation system. The decrease in the efficiency values of field water use of the sprinkler irrigation system and its increase using the drip irrigation system is attributed to the increase in the depths of water added when using the sprinkler irrigation system in addition to the decrease in the biological yield. On the other hand, the decrease in water productivity for irrigation level I\(_1\) is due to the use of fewer irrigations with a converging water depth compared to the irrigation level I\(_3\), which led to removing the nutrients below the root zone. Besides, a decrease in their concentrations and then a decrease in productivity, which in turn leads to a decrease in the efficiency of water use [20]. Otherwise, it may be attributed to the weakness of the root, which is reflected in the plant's ability to absorb water and nutrients, which in turn leads to a decrease in vegetative growth rates and the yield of tubers.

![Figure 8. The effect of irrigation level, potassium fertilization on the water productivity (kg m\(^{-3}\)) using the surface drip irrigation system](image)

3.2.4.2. Crop water use efficiency. Figure 9 shows the effect of irrigation level and potassium fertilization on the crop water use efficiency (kg m\(^{-3}\)) using the surface drip irrigation system. Thus, the highest crop water use efficiency in the I\(_3\)K\(_3\) treatment was 17.58 kg m\(^{-3}\), while the lowest value of the crop water use efficiency was 11.49 kg m\(^{-3}\) for the I\(_1\)K\(_1\) treatment. The crop water use efficiency for other irrigation treatments was 13.01, 13.93, 12.86, 14.39, 15.31, 14.79, and 15.96 kg m\(^{-3}\) for the treatments I\(_1\)K\(_2\), I\(_1\)K\(_3\), I\(_2\)K\(_1\), I\(_2\)K\(_2\), I\(_2\)K\(_3\), I\(_3\)K\(_1\), and I\(_3\)K\(_2\), respectively.
It is evident that the crop water use efficiency decreased with the irrigation level $I_1$ for the two irrigation systems used due to the interval between irrigations and thus caused a decrease in the yield of potatoes because the potatoes are sensitive to the interval between irrigations due to water stress. The increase in the crop water use efficiency at treatment $K_3$ is because potassium works to absorb nutrients and transfer water from the potato roots to the plant [25].

### 3.3. Total yield

The results of Figure 10 showed the effect of the triple interaction of the irrigation system, the irrigation level, and the potassium fertilization on the total yield of potatoes, as the highest yield reached 44.87 Mg ha$^{-1}$ at the surface drip irrigation system $T_1$, the irrigation level $I_3$ and the potassium fertilization $K_3$. This treatment differed significantly from the interaction treatments $T_1I_1K_1$ and $T_1I_1K_2$ and $T_1I_1K_3$, $T_1I_2K_1$, $T_1I_2K_2$, $T_1I_2K_3$, $T_2I_1K_1$, $T_2I_1K_2$, $T_2I_1K_3$, $T_2I_2K_1$, $T_2I_2K_2$, $T_2I_2K_3$, $T_2I_3K_1$, $T_2I_3K_2$, and $T_2I_3K_3$, where the average total yield were 29.45, 33.36, 35.71, 32.87, 36.79, 39.13, 37.75, 40.73, 26.18, 29.68, 34.71, 28.50, 2.43, 37.65, 32.12, 37.32 and 41.39 Mg ha$^{-1}$, respectively.

![Figure 9. The effect of irrigation level, potassium fertilization on the crop water use efficiency (kg m$^{-3}$) using the surface drip irrigation system](image)

![Figure 10. Effect of irrigation level, irrigation levels, potassium fertilization, and interactions on an average yield of potato (Mg ha$^{-1}$)](image)
Also, Figure 10 shows that the use of the surface drip irrigation system gave better results than the use of the sprinkler irrigation system. The reason may be due to the irrigation application efficiency, as it reached 91.27% when using the surface drip irrigation system. Besides, it decreased when using the sprinkler irrigation system, reaching 81.74%, with an increase of 11.66%, which leads to the addition of larger quantities of irrigation water when using the sprinkler irrigation system to supply the calculated water quantities for the treatments and the achieving soil moisture of the field capacity and the needs of the plant. Otherwise, the reason may be due to the irrigation system used, when using the surface drip irrigation system, water is added directly to the soil surface and the effective root area, thus reducing evaporation from the soil surface and the absence of losses of spray and deep leaching. Or the reason for this is that the irrigation method is one of the environmental factors that have priority in influencing the characteristics and quality of the yield through its impact on the stages of emergence and formation of explants and their growth. Water plays a major role in increasing the availability to absorb nutrients NPK and in the growth and division of cells and in the regularity of metabolism. As well as, being a solvent and a medium that transports these substances to the different parts of the plant as well as supplying the energy needed for photosynthesis processes in which organic food is synthesized [26]; [27]. The preference of the \(I_1\) irrigation level can be attributed to the appropriateness of the irrigation frequency adopted for this treatment to a greater degree than others, as the increase of the ratio of IW:CPE from the lowest value 0.7 to 1.3. The highest value was reflected in the increasing the number of irrigations during the season (irrigation frequency) at rates of 10, 13, and 17 irrigations for the surface drip irrigation system and 12, 15, and 18 irrigations for the sprinkler irrigation system for irrigation levels 0.7, 1.0 and 1.3, respectively, due to the decrease in the irrigation interval with an increase in PEF irrigation levels. This indicates that the irrigation interval that gave the best results was 6, 4, and 2 days, according to the growth stages (vegetative growth, Initiation and bulking of tubers and tuber maturity) for surface drip irrigation and sprinkler irrigation systems. Consequently, this was achieved the concept of modern irrigation systems by applying irrigation water in small quantities and at close intervals by achieving an appropriate irrigation interval and with an average depth of water added in one irrigation, as the average depth of water added per irrigation decreases with the increase of the IW:CPE ratio. This is consistent with the findings of [28]; [29]. Furthermore, increasing the yield of potatoes as a result of an increase in the level of potassium fertilizer, the reason may be due to the increase in the weight of tuber and to the increase in the number of tubers formed. This can be attributed to the fact that the addition of potassium leads to encouraging the growth of tubers through the distribution of stomata in the leaves, raising the leaf's efficiency in the metabolic process. Along with, increasing the transfer of materials to the tubers and to the role that potassium plays in the carbohydrates movement from their formation sites to their storage sites and in starch formation [30]; [31].

4. Conclusions

The potato yield increases with the use of the surface drip irrigation system, depending on the ratio of 1.3 IW: CPE and the level of potassium fertilization \(K_3\). The actual water consumption is 255.15 mm, and the highest rate of the total yield reaching 44.87 Mg ha\(^{-1}\), and the values of \(K_c\) were 0.38, 0.51, and 0.37 for the stage of vegetative growth, Initiation and bulking of tubers and tuber maturity, respectively. However, the highest water use was 17.58 kg m\(^{-3}\) and the highest efficiency of water use was 27.20 kg m\(^{-3}\). It is recommended to use an operating pressure of 50 kPa when using the surface drip irrigation system and operating pressure of 100 kPa when using a sprinkler system. It is also recommended to use the surface drip irrigation system in arid and semi-arid areas similar to the cultivated area.

References

[1] Waqas, M S, Cheema, MJM, Waqas, A and Hussain, S 2018, Enhancing Water Productivity of Potato (Solanum Tuberosum L.) Through Drip Irrigation System. Proceedings of Pakistan
Society for Horticultural Science, 18-20.

[2] Abd-El-Mooty, M, Kansoh, R and Abdulhadi, A 2016, Challenges of water resources in Iraq. Hydrology Current Research., 7(4), 1-8.

[3] Nikolau,G, Neocleous, D, Katsoulas, N, Kittas, C 2019, Irrigation of Greenhouse Crops. Horticulturae, 5, 7.

[4] Omran, ESE and Negm, AM 2020, Technological and Modern Irrigation Environment in Egypt: Best Management Practices and Evaluation. Springer Nature.

[5] Karim, LG, Mahood, NA and Allawi, MM 2019, Effect of irrigation intervals, biotic and abiotic treatments on water use efficiency, and Potatoes yield in Sulaimani–Iraqi Kurdistan region. Applied ecology and environmental research, 17(4), 10073-10090.

[6] Soil Survey 2014, Keys to soil Taxonomy. Agriculture Dept. (U. S.).

[7] Ali, Noureddine Shawky 2012, Fertilizer technologies and their uses. Ministry of Higher Education and Scientific Research. University of Baghdad, Iraq.

[8] Christiansen, JE 1942, Irrigation by Sprinkling University of California Agriculture Experiment Station Bulletin 670. Davis CA, 124 p.

[9] Anderson, CL, Bishop, AA, Hotes, F, Keller, J, Miller, JA, Pinney, J and Smerdon, E 1978. Describing irrigation efficiency and uniformity. J. Irr. Dra. Div., 104 (IRI):35-41.

[10] Al-Amoud, AI 1997, Drip Irrigation Systems. Agricultural Engineering Department. Faculty of Agriculture. King Saud University. Saudi Arabia.

[11] Hajim, AY and Yassin, HI 1992, Field Irrigation Systems Engineering. Dar Al-Kutub for printing and publishing. The University of Al Mosul.

[12] Nakayama, FS and Bucks, DA 1986, Trickle Irrigation for Crop Production Design, Operation and Management. Elsevier Science Publishers, PP.142-163.

[13] Camp, CR, Sadler, EJ and Busscher, WJ 1997, A comparison of uniformity measures for drip irrigation systems. Transactions of the ASAE. 40, 4, 1013-1020.

[14] Allen, RG, Pereira, LS, Raes, D and Smith, M 1998, Crop evapotranspiration. FAO Irrigation and Drainage. Paper 65, Rome.

[15] FAO/STAT 1998, Online statistical database of the food and Agricultural Organization of United Nations. http://faostat.fao.org./faostat

[16] Keller, J and Karmeli, D 1974, Trickle irrigation design parameters. Trans of ASAE., 17, 678-685.

[17] Schneider, AD, Howell, TA and Evett, RA 2001, Comparison of SDI, LEPA, and spray irrigation efficiency. An ASAE Meeting presentation. California. Paper No. 012019.

[18] Kincad, DC 1982. Sprinkler pattern radius. Published by the American Society for Agricultural Engineers, St. Joseph, Michigan., 25, 6,1668-1672.

[19] Sepaskhah, AR and Tafteh, A 2012, Yield and nitrogen leaching in rapeseed fields under different nitrogen rates and water-saving irrigation. Agricultural Water Management, 112, 55-62.

[20] Malooki, M M 2017, Effect of Moisture Depletion and Net Irrigation Depth on Some Physical Properties, Growth and Tomato Yield for Use Drip Irrigation. M.Sc. Thesis, Dept. of Soil Sci. and Water Resources, College of Agric. Univ. of Anbar/Iraq,1-105.

[21] Al-Dulaimy, SEH and Al-Mhmdy, SM 2018, Performance evaluation of drip irrigation system according to the suggested standards. The Iraqi Journal of Agricultural Science. 49(6), 1099.

[22] Ortega, JF, Tarjuelo, JM and de Juan, JA 2002. Evaluation of Drip Irrigation Performance in Localized Irrigation System of Semi-arid Regions (Castillala Moncha spain). Agricultural Engineering International: CIGR Journal of Scientific Research and Development, 4,1-17.

[23] Al -Kateeb, BA and Al -Shameri, A 2014, Evaluation of Some Drip Irrigation Systems Under Differential Operation Pressures. Al-Anbar, J. Agric. Sci.

[24] Zelelew, DZ, Lal, S, Kidane, TT and Ghebreslassie, BM 2016, Effect of potassium levels on
growth and productivity of potato varieties. *American Journal of Plant Sciences*, 7(12), 1629-1638.

[26] Li, C, Xiong, Y, Cui, Z, Huang, Q, Xu, X, Han, W and Huang, G 2020, Effect of irrigation and fertilization regimes on grain yield, water, and nitrogen productivity of mulching cultivated maize (*Zea mays* L.) in the Hetao Irrigation District of China. *Agricultural Water Management*, 232, 106065.

[27] Amaducci, S, Colauzzi, M, Battini, F, Fracasso, A and Perego, A 2016. Effect of irrigation and nitrogen fertilization on the production of biogas from maize and sorghum in a water-limited environment. *European Journal of Agronomy*, 76, 54-65.

[28] Biswal, S, Nedunchezhiyan, M and Mohapatra, PK 2017, Effect of irrigation schedule and fertilizer levels on growth and yield of sweet potato (*Ipomoea batatas* L.). *Journal of Root Crops*, 43(1), 44-51.

[29] Gogoi, M, Ray, LI, Sanjay-Swami, KK and Meena, NK 2020, Performance of potato variety Kufri Megha under different irrigation scheduling and date of planting at North Eastern Indian mid-hills. *Journal of Environmental Biology*, 41,1605-1610.

[30] Najem, NH, Al-Sahaf, FH and Albayati, HJ 2020, The effect of organic residues and spraying of potassium and zinc on some growth characteristics and yield of potato. *Plant Archives*, 20(2), 131-139.

[31] Koch, M, Busse, M, Naumann, M, Jakli, B, Cakmak, I, Hermans, C and Pawelzik, E 2019, Differential effects of varied potassium and magnesium nutrition on production and partitioning of photoassimilates in potato plants. *Physiol. Plant*, 166(4), 921-935.