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# Design of Closed-Circuit Drip Irrigation and Deficit Irrigation Scheduling Under Rotation Irrigation Systems to Improve Yield and Water Productivity of Potato Under Arid Climate Conditions

**Abdelraouf R.E.[1], Abdou M.A.A.[1], Abou-Hussein S.D.[2] and Mansour N.E.[3]**

[1]Water Relation and Field Irrigation Dept., Agricultural & Biological Research Institute, National Research Centre, 33 EL Buhouth St., Dokki, Giza, Egypt, Postal Code: 12622.
[2]Vegetable Research Dept., Agricultural & Biological Research Institute, National Research Centre (NRC), 33 El-Buhouth St., 12622 Dokki, Giza, Egypt.
[3]Agricultural and Natural Resources Engineering, Department of Agricultural Engineering, Faculty Damanhour University, Damanhour, Egypt.

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## ABSTRACT
Under the conditions of water scarcity in Egypt, there are many farms that follow the rotation irrigation system which add a large and more than necessary amount of water, as the entire weekly amount of water om only three days. This results in the loss of large amounts of irrigation water below the root zone, carrying with it and washing away the nutrients that are beneficial to the growth of the planted crops, which results in a decrease in crop productivity and water productivity and pollution of groundwater by increasing the washing of the relevant fertilizers dissolved in the escaping water downward. Two experiments were conducted during 2022/2023 and 2023/2024 At the National Research Centre (NRC) research farm in Nubaryia Region, Egypt to study the effect of closed-circuit drip irrigation (CCDI) system and the weekly irrigation deficit strategy was studied in an attempt to maximize the productivity and water productivity of the potato crop, which is one of the important vegetable crops that is grown in large areas in Egypt. It was found that the value of water emission uniformity with CCDI is greater than the water emission uniformity with the traditional open-circuit irrigation system (TDIS). The highest value of irrigation water application efficiency was achieved with CCDI when the irrigation deficit was scheduled at 40% of the full weekly irrigation over three days, although irrigation at 40% encountered the greatest soil moisture stress. The lowest value of irrigation water application efficiency was achieved with TDIS when the irrigation deficit was scheduled at 100% of the full weekly irrigation over three days, although irrigation at 100% encountered the least soil moisture stress. The lowest soil water stress values were achieved when designing TDIS with irrigation at 100% of the full weekly irrigation. The highest water stress values were also achieved with the TDIS with irrigation at 40% of the full weekly irrigation. The highest productivity and N-Uptake values were achieved with CCDI with the irrigation strategy at 80% and 60% of weekly irrigation for the rotation irrigation system. Based on achieving the highest value of productivity when studying the results of the interaction between the study factors, the highest value of crop water productivity was when applying CCDI and applying the irrigation deficit scheduling strategy at 60% of the full weekly irrigation to save 40% of irrigation water.

***Keywords:*** closed-circuit drip irrigation, irrigation scheduling, rotational irrigation system, Arid Climate Conditions, Sandy soils, Potato crop

## 1. Introduction
One of the riskiest and most significant issues facing Egypt's agricultural producers is water scarcity. There is a lot of pressure on the agricultural sector to cut back on water use so that freshwater can be made available for the industrial and urban sectors in arid nations where population growth is

**Corresponding Author:** Abdelraouf R.E., Water Relation and Field Irrigation Dept., National Research Centre, 33 EL Buhouth St., Dokki, Giza, Egypt, Postal Code: 12622.
Email: - abdelrouf2000@yahoo.com

rapid and freshwater resources are limited (Abdulraouf and Abuarab 2012). Increasing crop water productivity is one way to help the agriculture industry meet its significant challenge of producing more food with less water (Abdelraouf *et al.,* 2013 a). One of the key national objectives to meet the enormous demand of the rapidly growing human population is thought to be expanding yield output (Bakry *et al.,* 2012). When irrigation water supplies are few and rainfall is a limiting factor, water productivity is highly valued in Egypt (Hozayn et al, 2013). To mitigate this, new technologies must be developed that will enable farmers to use irrigation water more efficiently and profitably (Abdelraouf *et al.,* 2013 b). Because water resources are limited, applying contemporary irrigation techniques is a crucial idea that should be adhered to in arid countries like Egypt in order to save some irrigation water El-Habbasha *et al.,* 2014).

Systems for distributing irrigation water may have multiple goals, including timeliness, equity, and sufficiency. The canal networks that distribute irrigation water have varying design capacity, command regions, and lengths, necessitating varying operating durations. Under these circumstances, scheduling irrigation becomes more difficult, particularly for rotational irrigation water distribution. In certain systems, rotational irrigation water distribution has been implemented to address the shortfall and scarcity of irrigation water. Water distribution systems frequently aim to achieve multiple goals, including timeliness, equity, and sufficiency. The water distribution canal systems varied in their command regions, lengths, and design capacity, necessitating varying operating times. In these circumstances, scheduling irrigation, particularly for rotational water delivery, becomes a difficult task. Due to their pre-established mathematical structure or the computing demands of representing reality, optimization techniques are limited in the aforementioned scenarios. Compared to continuous watering, rotating irrigation scheduling is more complicated since it calls for more managerial input regarding the number of gate operations, monitoring locations, and gate operator travel distance. In these complicated conditions, the management needs specialized skills and knowledge to establish priorities for allocating irrigation water based on predetermined objectives, as well as to construct and implement an irrigation plan (Santhi and Pundarikanthan, 2000). In the past twenty years, the usage of soil microorganisms has expanded throughout the world due to the detrimental effects that chemical and mineral fertilizers have on the environment, as well as the rising expenses associated with them. (Abdelraouf *et al.,* 2013 a)

Water is customarily divided among branch canals in Egypt based on a rotation system that is commonly described as having two turns in the summer and three in the winter. This implies that a canal will usually be open for business for five days in the summer and closed for ten days in the winter. The canal's capacity and predicted total water requirement are typically used to determine how many days are "on." Ensuring the efficacy of the discharge during the "on" phase and the regularity of this cycle are the primary, albeit challenging, tasks of water management. A mismatch between supply and demand is the outcome of both time uncertainty and quantity availability, which also leads to risk-reduction tactics on the part of farmers. It makes sense to store water if the supply is unpredictable, and the only reservoir that farmers have access to is the soil profile. As a result, when water is available, farmers often overirrigate, which raises losses on these farms and deprives farmers farther downstream on the branch canal of water. Unpredictable water supply leads to sub-optimal crop irrigation, losses in yields and income, and prevents farmers from adopting more valuable cash crops (which require more cash investments that would be at risk), even though it is somewhat mitigated by the possibility for some farmers to abstract water from the aquifer or drains (Allam, 2004; Batt and Merkley, 2009).

The results show that increasing the number of irrigation days per week led to a slightly rise in citrus yields under a rotating irrigation scheme. In this regard, the average citrus yields for the two seasons (2016 and 2017) varied due to the implementation of weekly water requirements spread over three days. When comparing yield metrics such as number of fruits or kg/tree and ton.ha$^{-1}$, the three-day weekly irrigation strategy yielded the highest meaningful value when compared to one or two irrigation days per week. For the four citrus species included in the study, this was accurate. Regarding fruit qualities, the majority of the physical and chemical attributes were not significantly affected by any irrigation treatment. Citrus yield increases could be attributed to better irrigation water application efficiency, which was achieved by increasing the number of irrigation days per week. This would save the total amount of water that left the effective root zone through deep percolation, reducing water stress there and improving the fertigation process application (Abdelraouf *et al.,* 2018).

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The aim of this study was to maximize the productivity and water productivity of vegetables (Spunta potato variety as a case study) under rotation irrigation conditions by closed circuit drip irrigation and deficit irrigation strategies under arid climate conditions in Egypt.

## 2. Materials and Methods

### 2.1. The experimental site's location and climate

At the National Research Centre (NRC) research farm in Nubaryia Region, Al Buhayrah Governorate, Egypt (latitude 30o 30' 1.4"N, longitude 30o 19' 10.9" E, and 21m + MSL (mean sea level), field tests were carried out in 2022/2023 and 2023/2024. The climate of the experimental region is arid, with chilly winters and scorching, dry summers. The local weather station at El-Nubaryia Farm provided the maximum and minimum temperature, relative humidity, and wind speed data, as seen in Figure (1).

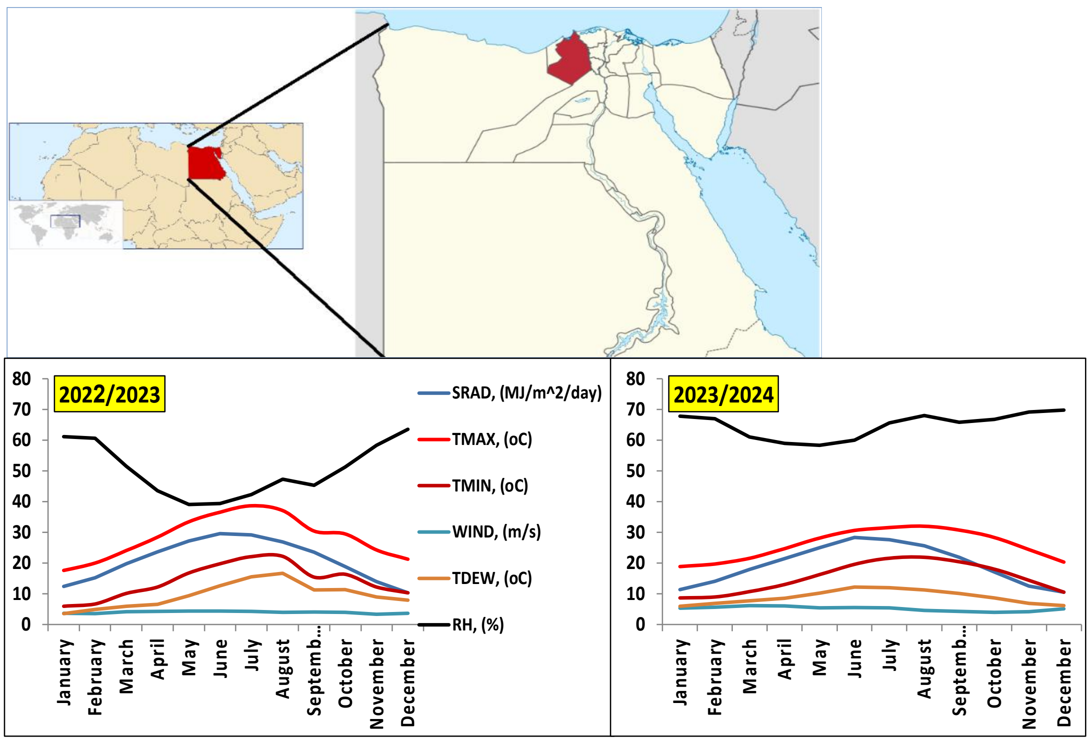



**Fig. 1:** Location coordinates of the experimental potato farm weather factors during the two study seasons.

### 2.2. Physical and chemical properties of irrigation water and soil

Table 1 displays the irrigation water's chemical properties. The experimental site's open irrigation channel provided the irrigation water, which had an average pH of 7.18 and electrical conductivity of 0.43 dS m-1 (Table 1). At the onset of the experiment, the primary physical and chemical characteristics of the soil, as presented in Table (2), were ascertained both in situ and in the laboratory.

**Table 1:** Chemical characteristics of the irrigation water

| Sodium Adsorption Ratio SAR | Anion (meq $L^{-1}$) | | | | Cation (meq $L^{-1}$) | | | | EC (dS $m^{-1}$) | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SO_4^{--}$ | $Cl^-$ | $HCO_3^-$ | $CO_3^{--}$ | $K^+$ | $Na^+$ | $Mg^{++}$ | $Ca^{++}$ | | |
| 2.68 | 1.43 | 1.74 | 1.14 | 0.74 | 0.33 | 2.61 | 0.64 | 1.47 | 0.43 | 7.18 |

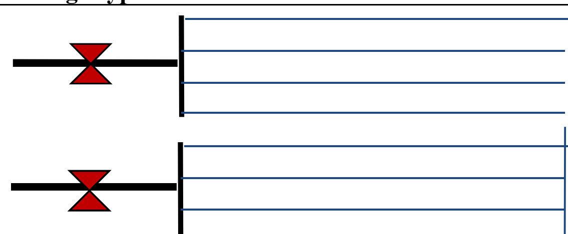
**Table 2:** The soil's physical and chemical characteristics in the experimental region

| | | | |
|---|---|---|---|
| | **Physical properties** | | |
| **Soil layer depth (cm)** | 0–15 | 15-30 | 30-45 |
| **Texture** | Sandy | Sandy | Sandy |
| **Coarse sand (%)** | 47.68 | 56.13 | 37.61 |
| **Fine sand (%)** | 48.91 | 40.61 | 58.47 |
| **Silt+ clay (%)** | 3.41 | 3.26 | 3.92 |
| **Bulk density (t $m^{-3}$)** | 1.68 | 1.69 | 1.66 |
| | **Chemical properties** | | |
| **$EC_{1:5}$ (dS $m^{-1}$)** | 0.54 | 0.64 | 0.71 |
| **pH (1:2.5)** | 8.58 | 8.73 | 9.04 |
| **Total $CaCO_3$ (%)** | 7.05 | 2.53 | 4.68 |

## 2.3. Experimental design

The experimental design used was split plot with three replicates. The main plots were devoted to the two irrigation treatments (TDIS and CCDI) while the sub ones were assigned for irrigation rates with four treatments (W1, W2, W3 and W4) and its details are as shown in the following Table 3.

**Table 3:** The experimental design details

| Main plot | Sub-main plot | Design type | Irrigation system |
|---|---|---|---|
| TDIS | W1 |  | Drip irrigation |
| | W2 | | |
| | W3 | | |
| | W4 | | |
| CCDI | W1 | | |
| | W2 | | |
| | W3 | | |
| | W4 | | |

TDIS: Traditional drip irrigation system; CCDI: Closed-Circuit Drip Irrigation; W1: 100% of the weekly irrigation water quantity added over three days; W2: 80% of the weekly irrigation water quantity added over three days; W3: 60% of the weekly irrigation water quantity added over three days; W4: 40% of the weekly irrigation water quantity added over three days

**2.4. Irrigation requirements of potato:** Irrigation requirements of potato was calculated by following equation (1) under drip irrigation system:

$$IRg = [(ET_O \times Kc \times Kr) / IE] - R + LR \quad \text{……………………………..……………………….……….} (1)$$

Where: IRg = Gross irrigation requirements, mm/day,
Kc = Crop factor (FAO-56)
$ET_O$ = Reference evapotranspiration, mm/day and represents the reference evapotranspiration in mm/day and for calculating ETo can be expressed as (Allen *et al.,* 1998) using Equation (2):

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T_a + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad \text{…………………………………………………………..…..} (2)$$

The values of the following are given: Ta is the average daily air temperature at 1.5–2.5 m height (°C), u2 is the mean daily wind speed at 2 m height (m $s^{-1}$), es is the saturation vapor pressure (kPa), and ea is the actual vapor pressure (kPa). Additionally, Rn is the net radiation at the crop surface (MJ$m^{-2}$ $day^{-1}$), G is the soil heat flux density at the soil surface (MJ$m^{-2}$ $day^{-1}$), and γ is the psychrometric constant (kPa $°C^{-1}$). The closest weather station gathered all meteorological data for the farm's research site. The Penmen-Monteith equation was used to estimate the daily evaporation values for the Nubaryia Region, Al Buhayrah Governorate, Egypt, once the relevant meteorological data was obtained, as shown in Figure (5).

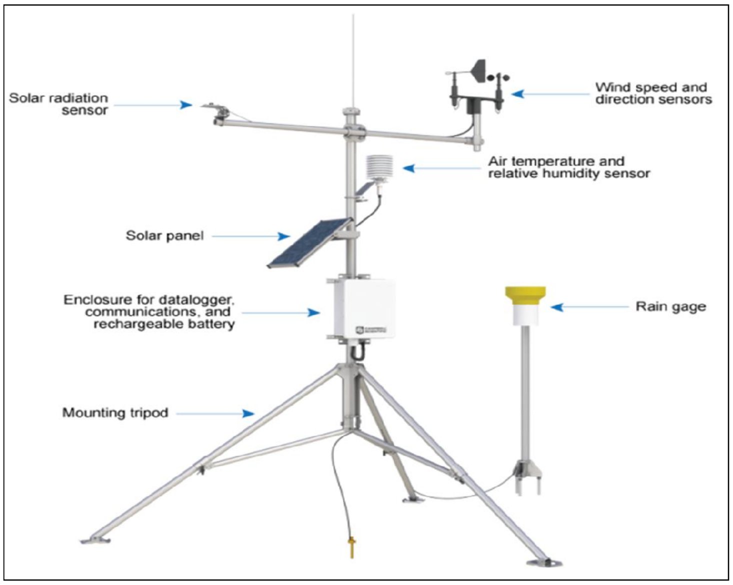



**Fig. 2:** The same weather station components that were present on the farm during the two planting seasons of the potato experiment in Nubaryia Region, Al Buhayrah Governorate, Egypt

Kr = Ground cover reduction factor and the values of Kr measured by Keller equation (3):

Kr = GC% + 0, 15. (1 – GC %) ………………………………………………………………..…….(3)

Where GC%: ground cover = (shaded area per plant/area per plant)
IE = Irrigation efficiency, %, R = Water received by plant from sources other than irrigation, mm (for example rainfall), LR = Amount of water required for the leaching of salts, mm

**Table 4:** Total irrigation requirements for each treatment for both potato growing seasons

| Planting Season Dates | Main plot | Sub-main plot | Water emission uniformity, % | Irrigation water volume, $m^3$/fed/season |
|---|---|---|---|---|
| 2022/2023 | TDIS | W1 | 90.5 | 1800 |
| | | W2 | | 1440 |
| | | W3 | | 1080 |
| | | W4 | | 720 |
| | CCDI | W1 | 95.2 | 1705 |
| | | W2 | | 1364 |
| | | W3 | | 1023 |
| | | W4 | | 682 |
| 2023/2024 | TDIS | W1 | 90.0 | 1780 |
| | | W2 | | 1424 |
| | | W3 | | 1068 |
| | | W4 | | 712 |
| | CCDI | W1 | 94.7 | 1692 |
| | | W2 | | 1354 |
| | | W3 | | 1015 |
| | | W4 | | 677 |

TDIS: Traditional drip irrigation system; CCDI: Closed-Circuit Drip Irrigation; W1: 100% of the weekly irrigation water quantity added over three days; W2: 80% of the weekly irrigation water quantity added over three days; W3: 60% of the weekly irrigation water quantity added over three days; W4: 40% of the weekly irrigation water quantity added over three days

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### 2.5. Evaluation Parameters

#### 2.5.1. Water emission uniformity (EU)

Emission uniformity EU is defined to show the variation by the ratio of the minimum to the mean. The ratio of the minimum emitter flow rate to the mean emitter flow rate represents the emission uniformity for drip irrigation (Keller & Karmeli, 1974). Equation 4 was used to determine the water emission uniformity (EU) along the drip irrigation system's laterals in each plot area under a pressure range of 1.0 bar utilizing 20 collection cans.

$$EU = (qm / qa) \times 100 \quad (4)$$

Where EU is the water emission uniformity, %; qm is the average flow rate of the emitters in the lowest quartile, (l/h); and qa is the average flow rate of all tested emitters under test (l/h).

#### 2.5.2. Water Application efficiency "WAE”

In regard to the amount of water applied to the field, WAE refers to the actual storage of water in the root zone to meet crop water needs. El-Meseery (2003) states that the WAE was determined by applying the relation (5) below:

$$WAE = Ds / Da \quad (5)$$

Where:
WAE: Water application efficiency (%), Da: Depth of irrigation water to be added, Ds: calculated root zone water storage depth (cm) and $Ds = (\Theta_1 - \Theta_2) \times d \times \sigma$, where $\Theta_1$ denotes the average moisture content of the soil after irrigation, $\sigma$ denotes the relative bulk density of soil (dimensionless), $\Theta_2$ denotes the average moisture content of the soil before irrigation, and d denotes the depth of the soil layer as shown in Figure 3.

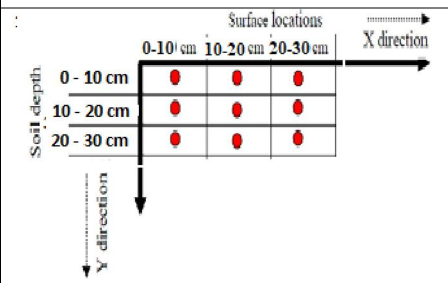
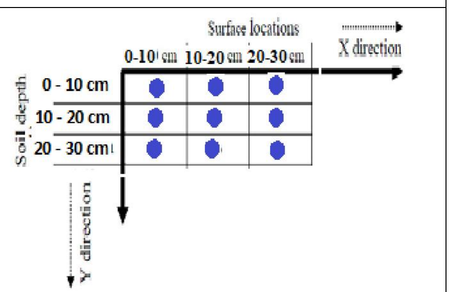
<table>
<tr><td>Soil moisture content</td><td>Before irrigation</td><td>After irrigation</td></tr>
<tr><td>Soil moisture measurement sites in the root zone</td><td>
</td><td>
</td></tr>
<tr><td>Symbol</td><td>Average $\Theta_2$</td><td>Average $\Theta_1$</td></tr>
</table>

**Fig 3:** Estimating method of water application efficiency at peak water requirements are required during the potato growing season.

#### 2.5.3. Water stress

Measurement of the soil moisture content in the effective root zone prior to irrigation, using the wilting point and field capacity as assessment lines, is thought to be an evaluation parameter for the plants' exposure range to water stress ("WS") (Abdelraouf, 2014). A profile probe instrument was used to measure the moisture content of the soil. Measurements of soil moisture were taken prior to each irrigation event during the whole growing season in order to assess the water stress that crop plants were subjected to in their root zone, as seen in Figure (4). Before irrigation, the average moisture content for each treatment was noted. The difference between the soil moisture content before to irrigation and the wilting point was used to calculate the amount of water stress in the rhizosphere.

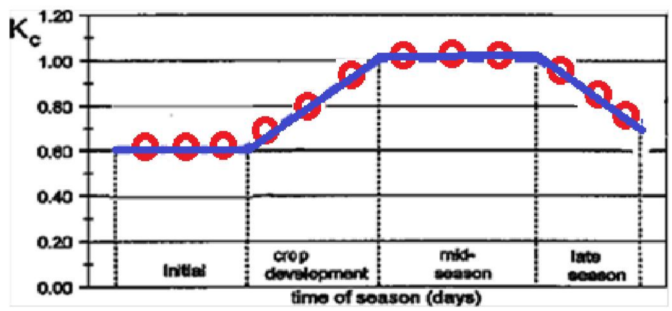
| | |
|---|---|
|   |  |
| Stages of growing season | Profile probe device |

**Fig. 4:** Locations for measuring moisture content within the root zone before irrigation during the four stages of potato plant growth

**2.5.4. Yield of potato:** At harvest, yield as kg per $m^2$ and converted to ton per feddan.
**2.5.5. Nitrogen uptake (N-Uptake):** The N-uptake is obtained by multiplying the N concentration with dry matter and dividing with 100.
**2.5.6. Water productivity of potato** "$WP_{potato}$" was calculated according to James, (1988) by equation (6) as follows:

$$WP_{potato} = Ey/Ir \quad \text{.......... (6)}$$

Where: $WP_{potato}$ is water productivity of potato ($kg_{potato}$ / $m^3$ $_{irrigation\ water}$), Ey is the economical yield (kg $_{potato}$ /fed.); Ir is the applied volume of irrigation water ($m^3$ $_{irrigation\ water}$ /fed./season).

### 2.6. Statistical Analysis

Snedecor and Cochran's (1980) analysis of variance method was used to statistically examine all the data collected throughout the two combined seasons of the study. Nonetheless, the Duncan's multiple range test allowed for the distinction of means (Duncan, 1955).

## Results and Discussion

Due to the limited water resources in Egypt, the Ministry of Water Resources is forced to apply the rotation irrigation system in sandy desert areas. The rotation irrigation system is known as pumping irrigation water into the water channels intermittently and not continuously. There is what is known as the second rotation irrigation system, which is pumping water for three days and not pumping for four days. Farms that follow this rotation irrigation system add a large and more than necessary amount of water, as the entire weekly amount of water is added on only three days, which are the working irrigation days. This results in the loss of large amounts of irrigation water below the root zone, carrying with it and washing away the nutrients that are beneficial to the growth of the planted crops, which results in a decrease in crop productivity and water productivity and pollution of groundwater by increasing the washing of the relevant fertilizers dissolved in the escaping water downward. The effect of the closed-circuit drip irrigation system and the weekly irrigation deficit strategy was studied in an attempt to maximize the productivity and water productivity of the potato crop, which is one of the important vegetable crops that is grown in large areas in Egypt. The following evaluation criteria illustrate the most important parameters that must be applied to achieve the objective of the study.

### 3.1. Water emission uniformity

Figure (5) confirmed that there is a clear effect of the closed-circuit drip irrigation system on increasing the water emission uniformity compared to the traditional irrigation system. Two drip irrigation systems were designed at the experimental site, a closed-circuit drip irrigation system and another traditional open-circuit irrigation system. The water emission uniformity was measured for each system separately. It was found that the value of water emission uniformity with the closed-circuit drip irrigation system is greater than the water emission uniformity with the traditional open-circuit irrigation system. This was due to the increase in the average discharge by the least quarter of the irrigation network divided by the average total discharge of the network as a whole according to the following relationship:

EU = (qm / qa) × 100………………………………………………………………………….(7)

Where EU is the water emission uniformity, %; qm is the average flow rate of the emitters in the lowest quartile, (l/h); and qa is the average flow rate of all tested emitters under test (l/h).

The reason for the increase in the average discharge by the least quarter in the closed-circuit drip irrigation system was due to the equalization of water pressures in the branch network compared to the traditional open-circuit drip irrigation network, which has large differences in pressures, which resulted in a large difference in discharges and a decrease in the water emission uniformity in it.

Figure (5) also showed that by increasing the water emission uniformity of the closed-circuit drip irrigation system, the amount of water required for irrigation and that must be added to irrigate and grow potato plants decreased compared to the traditional open drip irrigation system. The results obtained from this study agreed with both Tayel *et al.,* (2012); Kirnak *et al.,* (2004) and Abdelraouf *et al.,* (2018).

There is no effect on the volume of irrigation water required to be added and the water emission uniformity, as the water emission uniformity expresses the design performance of the irrigation network itself as it was estimated at W1 (100% full irrigation) and was not estimated at W2 (80% FI) or W3 (60%FI) or even at W4 (40%FI).

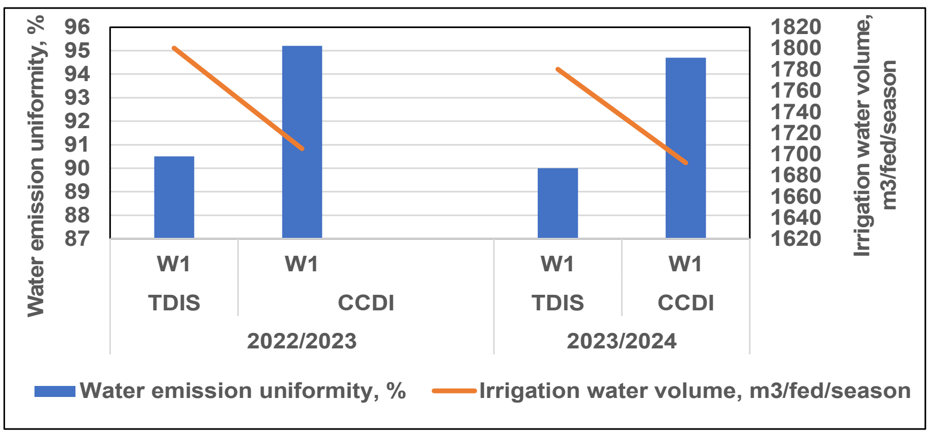



**Fig. 5:** Effect of closed-circuit drip irrigation on the Water emission uniformity and its relationship to the amount of irrigation water required for potato growth.

### 3.2. Water application efficiency

The data presented in Figure (6) showed the significant effect of the closed design of the drip irrigation system and the strategies of drip irrigation scheduling deficit under the dual rotation irrigation system in sandy soils.

The water addition efficiency values with the closed-circuit drip irrigation system were greater than the water addition efficiency values under the traditional open drip irrigation system. This was due to the increased regularity of water distribution in addition to the lower volume of irrigation water required to be added compared to the traditional open drip irrigation system which suffered from lower regularity of water distribution and also the volume of irrigation water added was large which led to a larger volume escaping to the bottom of the root zone.

There was a clear and significant effect on increasing the water application efficiency values with decreasing the volume of added irrigation water and vice versa, as shown in Figure (6). This is due to the fact that with decreasing irrigation water volume, the volume of irrigation water stored within the root spread zone increases and the part escaping below the root spread zone decreases, while with increasing the volume of added irrigation water, the volume of water escaping below the root zone increases. The above indicates that the water application efficiency value at W1 is less than W2, the latter is less than W3, and the latter is less than W4, which means that the highest Water application efficiency values were achieved at W4 and the lowest values were achieved at W1.

The highest value of irrigation water application efficiency was achieved with the closed drip irrigation design when the irrigation deficit was scheduled at 40% of the full weekly irrigation over three days, although irrigation at 40% encountered the greatest soil moisture stress. The lowest value of irrigation water application efficiency was achieved with the traditional open drip irrigation design when the irrigation deficit was scheduled at 100% of the full weekly irrigation over three days, although irrigation at 100% encountered the least soil moisture stress.

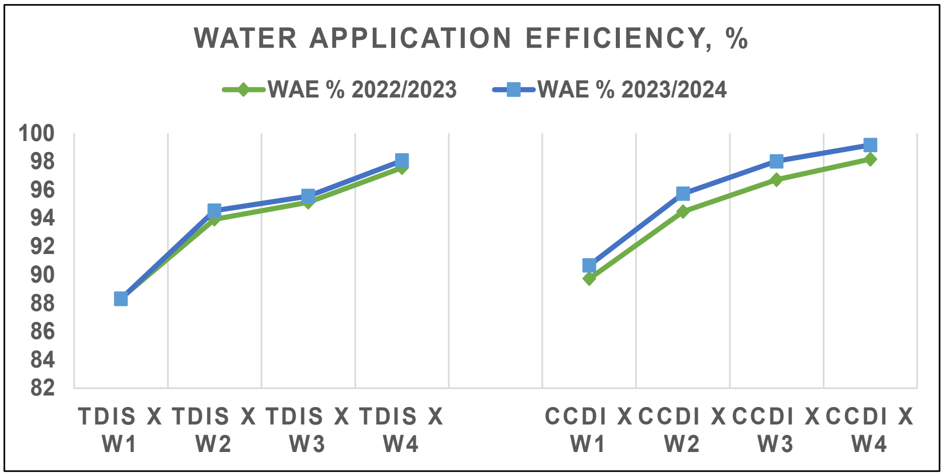



**Fig. 6:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the water application efficiency (WAE).

### 3.3. Water stress on potato plant roots

The best way to study water stress within the root zone is the soil moisture content of the root zone before each irrigation process during the growing season for all four growth stages of the planted crop plants. The average soil moisture content was calculated for each treatment under study after collecting the soil moisture content values of the root zone before each irrigation process during the four growth stages.

Figure (7) confirmed that there is a clear effect of the closed-circuit drip irrigation system and deficit irrigation scheduling strategies on the soil moisture content values of the root zone before irrigation. There was a slight increase in the soil moisture content values of the root zone before irrigation with the closed-circuit drip irrigation system compared to the traditional open-circuit drip irrigation. This is due to the fact that the closed-circuit drip irrigation led to an increase in the regularity of water distribution within the entire field, which led to equalization of the water stresses of the root zones in the entire field and a decrease in the areas with high stress and the areas with small water stress, while this did not happen with the traditional open-circuit drip irrigation system.

Figure (7) shows that by increasing the volume of added irrigation water, the ground water stress values decrease and areas become less stressful for the growth of the roots of the planted plants, and this is not true.

The lowest ground water stress values were achieved when designing closed-circuit drip irrigation with irrigation at 100% of the full weekly irrigation and its volume was added over only three days according to the dual irrigation rotation. The highest water stress values were also achieved with the traditional open-circuit drip irrigation design with irrigation at 40% of the full weekly irrigation and its volume was added over only three days.

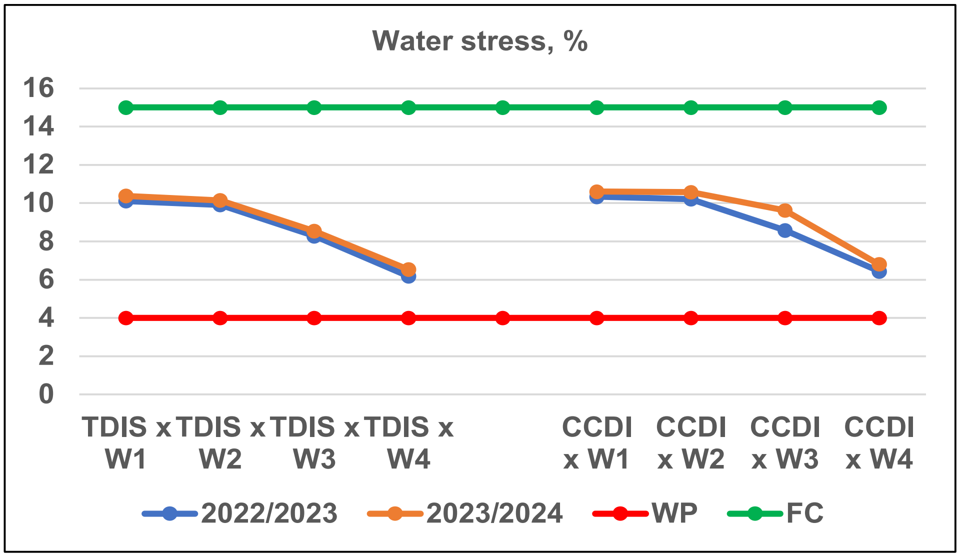



**Fig. 7:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the water stress on potato plant roots.

**Table 5:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the water application efficiency and water stress on potato plant roots

| Treatments | WAE % | | Water stress, % | |
|---|---|---|---|---|
| | 2022/2023 | 2023/2024 | 2022/2023 | 2023/2024 |
| **TDIS** | 93.74 b | 94.12 b | 8.608 b | 8.89 |
| **CCDI** | 94.78 a | 95.90 a | 8.883 a | 9.40 |
| **LSD at α .05** | 1.009 | 1.739 | 0.176 | N.S |
| **W1(100%FI)** | 89.03 d | 89.48 d | 10.22 a | 10.48 |
| **W2 (80%FI)** | 94.2 c | 95.13 c | 10.05 a | 10.35 |
| **W3 (60%FI)** | 95.93 b | 96.80 b | 8.417 b | 9.08 |
| **W4 (40%FI)** | 97.87 a | 98.62 a | 6.3 c | 6.67 |
| **LSD at α .05** | 0.66 | 0.57 | 0.21 | 0.12 |
| **TDIS x W1** | 88.33 | 88.30 f | 10.10 | 10.37 |
| **TDIS x W2** | 93.93 | 94.53 d | 9.90 | 10.13 |
| **TDIS x W3** | 95.13 | 95.57 c | 8.27 | 8.53 |
| **TDIS x W4** | 97.57 | 98.07 b | 6.17 | 6.53 |
| **CCDI x W1** | 89.73 | 90.67 e | 10.33 | 10.60 |
| **CCDI x W2** | 94.47 | 95.73 c | 10.20 | 10.57 |
| **CCDI x W3** | 96.73 | 98.03 b | 8.57 | 9.62 |
| **CCDI x W4** | 98.17 | 99.17 a | 6.43 | 6.80 |
| **LSD at α .05** | N.S | 0.800 | N.S | N.S |

TDIS: Traditional drip irrigation system; CCDI: Closed-Circuit Drip Irrigation; W1: 100% of the weekly irrigation water quantity added over three days; W2: 80% of the weekly irrigation water quantity added over three days; W3: 60% of the weekly irrigation water quantity added over three days; W4: 40% of the weekly irrigation water quantity added over three days; WAE: Water Application efficiency; Means followed by the different letters within each column significantly differ according to the Duncan multiple comparison test at the 5% level.; Each value is the average of three replicates over two seasons; NS: non-significant.

### 3.4. Yield of potato

The criterion for evaluating crop productivity is the main goal of any scientific development. The results obtained from this study showed significant differences between productivity values in each treatment.

Figure (8) and Table (6) confirmed the significant effect of the closed-circuit drip irrigation design and the weekly irrigation deficit scheduling for the dual rotation.

The productivity values with the closed-circuit drip irrigation design were greater than the productivity values with the traditional open-circuit drip irrigation design. This was due to the decrease and improvement of the ground water stress condition with the closed-circuit drip irrigation design, which led to an increase in the absorption of water and nutrients from the soil compared to the traditional open-circuit drip irrigation system, which was marred by the large variation in water stresses of the root zone throughout the entire field surface area, which led to a decrease in total productivity and these results were in agreement with Mansour *et al.,* (2010); Allam, (2004); Batt and Merkley, (2009).

Figure (8) and Table (6) showed the significant effect of the full weekly irrigation deficit scheduling and the addition of irrigation water volume to it over three days according to the dual rotation irrigation system on productivity values. Unexpectedly, the highest productivity values were obtained when irrigating with 80% and 60% of the full weekly irrigation schedule, while the productivity values were lower than those when irrigating with 100% and 40% of the full weekly irrigation schedule. This is due to the fact that reducing the volume of added irrigation water causes two opposite dynamic stress states, namely water stress and fertilization stress in the root zone. When adding a large volume of irrigation water (100% of the weekly irrigation), water stress decreases and fertilization stress increases by washing away nutrients from the root zone, which leads to increased water absorption and decreased nutrient absorption, which negatively affects crop productivity due to lack of nutrients, while when adding a small volume of irrigation water (40% of the weekly irrigation), water stress increases and fertilization stress decreases, which leads to increased concentration of fertilizer elements in the root zone, but there is weakness in their absorption as a result of water stress. The balance between water stress and fertilization stress occurred when irrigating with 80% and 60% of weekly irrigation, which resulted in achieving the highest productivity values when irrigating with them, and the differences were not significant between the two highest productivity values during the two harvest seasons and these results were in agreement with Abdelraouf *et al.,* (2018).

When studying the interaction between the study factors, the highest productivity values were achieved with the closed-circuit drip irrigation design with the irrigation strategy at 80% and 60% of weekly irrigation for the rotation irrigation system.

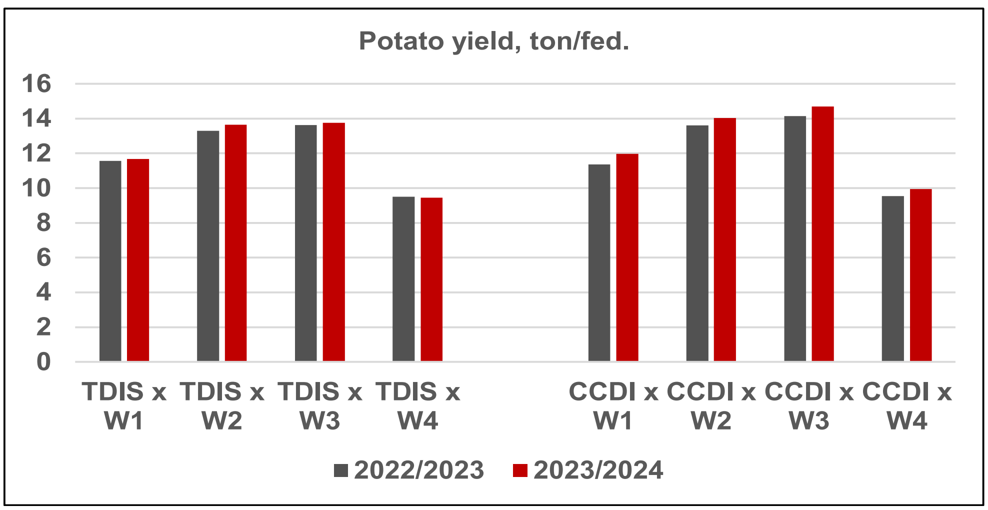



**Fig. 8:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the yield of potato.

### 3.5. Nitrogen uptake (N-Uptake)

To measure the N-Uptake and its concentration in the dry matter of potato tubers immediately after harvesting at the end of each season, the tubers were dried and the nitrogen content was determined, then the concentration was multiplied by the dry matter productivity of potato tubers.

Figure (9) and Table (6) confirmed the increase in the nitrogen uptake values with the closed-loop drip irrigation design compared to the traditional open drip irrigation. This is due to the increase in nitrogen absorption in the design that achieved the least stress on soil moisture in the root zone, which led to an increase in nitrogen absorption.

Figure (9) and Table (6) showed the significant effect of the full weekly irrigation deficit scheduling and the addition of irrigation water volume to it over three days according to the dual rotation irrigation system on N-Uptake values. Unexpectedly, the highest N-Uptake values were obtained when irrigating with 80% and 60% of the full weekly irrigation schedule, while the N-Uptake values were lower than those when irrigating with 100% and 40% of the full weekly irrigation schedule. This is due to the fact that reducing the volume of added irrigation water causes two opposite dynamic stress states, namely water stress and fertilization stress in the root zone. When adding a large volume of irrigation water (100% of the weekly irrigation), water stress decreases and fertilization stress increases by washing away nutrients from the root zone, which leads to increased water absorption and decreased nutrient absorption, which negatively affects N-Uptake due to lack of nutrients, while when adding a small volume of irrigation water (40% of the weekly irrigation), water stress increases and fertilization stress decreases, which leads to increased concentration of fertilizer elements in the root zone, but there is weakness in their absorption as a result of water stress. The balance between water stress and fertilization stress occurred when irrigating with 80% and 60% of weekly irrigation, which resulted in achieving the highest N-Uptake values when irrigating with them, and the differences were not significant between the two highest N-Uptake values during the two harvest seasons.

When studying the interaction between the study factors, the highest N-Uptake values were achieved with the closed-circuit drip irrigation design with the irrigation strategy at 80% and 60% of weekly irrigation for the rotation irrigation system.

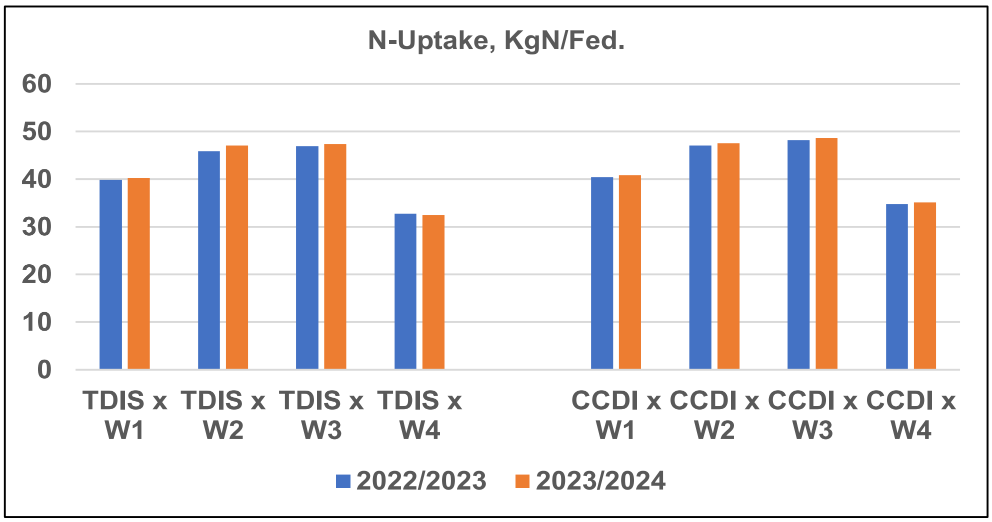



**Fig. 9:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the nitrogen uptake

### 3.6. Water productivity of potato

The water productivity of the crop is defined as the quotient of the economic crop productivity in kilograms divided by the total volume of irrigation water added in cubic meters from the beginning of cultivation until harvest.

Table (6) confirmed that the water productivity values when designing a drip irrigation system with closed circuits are greater than the water productivity values when designing a traditional open drip irrigation system. This was due to the increase in the crop productivity per feddan of potatoes with a decrease in the volume of added irrigation water due to the increase in the efficiency of regularity of irrigation water distribution in the field as a whole with the design of a drip irrigation system with closed irrigation circuits, unlike what was in the traditional open irrigation system.

Table (6) showed the significant effect of the full weekly irrigation deficit scheduling on water productivity of potato values. Although the highest water productivity values were achieved at 40% of the full weekly irrigation, the highest crop productivity was not achieved at 80% and 60% of the full weekly irrigation. Since the highest productivity values were achieved at 80% and 60% of the full weekly irrigation and the difference between them was not significant, the irrigation treatment at 60% of the full weekly irrigation was chosen to save more irrigation water, which was estimated to save 40% of the irrigation water to irrigate other new areas.

Based on achieving the highest value of productivity when studying the results of the interaction between the study factors, the highest value of crop water productivity was when applying the closed-circuit drip irrigation design and applying the irrigation deficit scheduling strategy at 60% of the full weekly irrigation.

**Table 6:** Effect of closed-circuit drip irrigation and deficit irrigation scheduling under rotation irrigation systems on the Potato yield, N-Uptake and water productivity of potato

| Treatments | Potato yield, ton/fed. | | N-Uptake, KgN/Fed. | | WP of potato, kg/m$^3$ | |
|---|---|---|---|---|---|---|
| | 2022/2023 | 2023/2024 | 2022/2023 | 2023/2024 | 2022/2023 | 2023/2024 |
| **TDIS** | 12 b | 12.14 b | 41.39 b | 41.86 | 10.37 | 10.58 |
| **CCDI** | 12.16 a | 12.67 a | 42.64 a | 43.07 | 11.11 | 11.66 |
| **LSD at α .05** | 0.096 | 0.111 | 1.227 | 1.193 | | |
| **W1(100%FI)** | 11.47 b | 11.83 b | 40.18 b | 40.58 | 6.55 | 6.82 |
| **W2 (80%FI)** | 13.44 a | 13.85 a | 46.47 a | 47.33 | 9.6 | 9.98 |
| **W3 (60%FI)** | 13.89 a | 14.23 a | 47.61 a | 48.10 | 13.22 | 13.68 |
| **W4 (40%FI)** | 9.525 c | 9.70 c | 33.81 c | 33.85 | 13.6 | 13.99 |
| **LSD at α .05** | 0.520 | 0.232 | 1.171 | 1.113 | | |
| **TDIS x W1** | 11.57 | 11.69 d | 39.93 | 40.33 | 6.43 | 6.57 |
| **TDIS x W2** | 13.29 | 13.65 c | 45.84 | 47.10 | 9.23 | 9.59 |
| **TDIS x W3** | 13.62 | 13.76 bc | 46.98 | 47.46 | 12.61 | 12.88 |
| **TDIS x W4** | 9.51 | 9.44 f | 32.81 | 32.55 | 13.21 | 13.26 |
| **CCDI x W1** | 11.36 | 11.97 d | 40.43 | 40.84 | 6.66 | 7.07 |
| **CCDI x W2** | 13.60 | 14.04 b | 47.09 | 47.56 | 9.97 | 10.37 |
| **CCDI x W3** | 14.15 | 14.70 a | 48.25 | 48.73 | 13.83 | 14.48 |
| **CCDI x W4** | 9.54 | 9.96 e | 34.80 | 35.15 | 13.99 | 14.71 |
| **LSD at α .05** | N.S | 0.328 | N.S | N.S | | |

TDIS: Traditional drip irrigation system; CCDI: Closed-Circuit Drip Irrigation; W1: 100% of the weekly irrigation water quantity added over three days; W2: 80% of the weekly irrigation water quantity added over three days; W3: 60% of the weekly irrigation water quantity added over three days; W4: 40% of the weekly irrigation water quantity added over three days; Means followed by the different letters within each column significantly differ according to the Duncan multiple comparison test at the 5% level.; Each value is the average of three replicates over two seasons; NS: non-significant.

## 4. Conclusion

Farms that follow this rotation irrigation system add a large and more than necessary amount of water, as the entire weekly amount of water is added on only three days, which are the working irrigation days. This results in the loss of large amounts of irrigation water below the root zone, carrying with it and washing away the nutrients that are beneficial to the growth of the planted crops, which results in a decrease in crop productivity and water productivity and pollution of groundwater by increasing the washing of the relevant fertilizers dissolved in the escaping water downward. The effect of the closed-circuit drip irrigation system and the weekly irrigation deficit strategy was studied in an attempt to maximize the productivity and water productivity of the potato crop, which is one of the important vegetable crops that is grown in large areas in Egypt.

It was found that the value of water emission uniformity with the closed-circuit drip irrigation system is greater than the water emission uniformity with the traditional open-circuit irrigation system. This was due to the increase in the average discharge by the least quarter of the irrigation network divided by the average total discharge of the network.

The highest value of irrigation water application efficiency was achieved with the closed drip irrigation design when the irrigation deficit was scheduled at 40% of the full weekly irrigation over three days, although irrigation at 40% encountered the greatest soil moisture stress. The lowest value of irrigation water application efficiency was achieved with the traditional open drip irrigation design when the irrigation deficit was scheduled at 100% of the full weekly irrigation over three days, although irrigation at 100% encountered the least soil moisture stress.

The lowest soil water stress values were achieved when designing closed-circuit drip irrigation with irrigation at 100% of the full weekly irrigation and its volume was added over only three days according to the dual irrigation rotation. The highest water stress values were also achieved with the traditional open-circuit drip irrigation design with irrigation at 40% of the full weekly irrigation and its volume was added over only three days.

The highest productivity and N-Uptake values were achieved with the closed-circuit drip irrigation design with the irrigation strategy at 80% and 60% of weekly irrigation for the rotation irrigation system.

Based on achieving the highest value of productivity when studying the results of the interaction between the study factors, the highest value of crop water productivity was when applying the closed-circuit drip irrigation design and applying the irrigation deficit scheduling strategy at 60% of the full weekly irrigation to save 40% of irrigation water.

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