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Management of Drip Irrigation and Fertilizer Injection on Potato Crop in Semi-Arid Climate

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Abstract:
This study was carried out to investigate the effect of water regime under a drip irrigation system on growth, tuber quality, leaf total chlorophyll, free proline and mineral composition, and water relations of potato crops during 2021-2022 growing season of the potato crop. The texture of the experimental site was sandy. Imported potato tuber seeds (Solanum tuberosum, L.) of Diamond cultivar were used in the present study. Planting was done in October 2021, in wet soil. The potato tuber seeds were planted at 0.22 m apart, in rows of 0.80 m width and 40.0 m length. Irrigation water was applied throughout a drip irrigation network using drippers of 3.0 L/hr capacity. The irrigation water was applied at six frequencies: 50, 75, 100, and 125% of reference evapotranspiration. The results revealed that foliage characteristics (i.e., plant height, shoot fresh weight, shoot dry weight, shoot dry matter and shoot water content) were significantly affected by the irrigation regime, in which increasing the amount of Irrigation water increased the vegetative growth. The data also, clearly indicated that increasing irrigation significantly increased leaf characteristics (total chlorophyll, leaf water contents i.e., free water content (FWC), bound water content (BWC), total water content (TWC), and relative water content (RWC)). Leaf proline content substantially increased with increasing water stress (decreasing the amount of irrigation water). Increasing the amount of irrigation water resulted in increasing the leaf nutrient content. Irrigation at 100% of ET0 resulted in improving the potato tuber's physical and chemical characteristics. The maximum tubers yield was attained at 100% of ET0 treatment (32.36 tons/ha.). In addition, the maximum water use efficiency was attained at the same level of irrigation water (17.249 kg tubers/ m3 of applied water). The most soil moisture was extracted from the top 40 cm soil layer. The moisture extraction was increased significantly with increasing the amount of irrigation water. The optimum soil moisture tension for potato crops was between 0.25 and 0.35 bar. The most important outcomes from the present study are clarifying the important role of irrigation regime with drip irrigation system in improving potato growth and tuber yield. Also, good distribution of moisture overall the root zone depth, can enhance the plant growth and yield of potato crops. The present study recommends 90% of ET0 (1238.3 m3 of applied water/fed) to achieve the highest potato yield and tuber quality under the same present conditions.

Keywords: Potatoes, Drip Irrigation, Reference Evapotranspiration, Water-Use Efficiency, Soil Moisture, Water Stress.

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إدارة عمليات الري بالتنقيط والسماد المحقون على محصول البطاطس في المناخ شبه الجاف

أشرف يعقوب سويدان [1]، نورالدين سالم بلق [2*]، نسرين المبروك قريميدة [3]
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الملخص
أجريت هذه الدراسة لمعرفة تأثير النظام المائي تحت نظام الري بالتنقيط على النمو، جودة الدرنات الكلوروفيل الكلي للأوراق، البرولين الحر والتركيب المعدني وكذلك العلاقات المائية لمحصول البطاطس خلال موسم النمو 2022/2021 لمحصول البطاطس كان نسيج الموقع التجريبي رمليًا استخدمت بذور درنات البطاطس المستوردة (Solanum tuberosum، L.) من صنف Diamont في هذه الدراسة، تمت الزراعة في أكتوبر 2021، في التربة الرطبة. زرعت بذور درنات البطاطس على مسافة 0.22 متر في صفوف بعرض 0.80 متر وطول 40.0 متر. تم استخدام مياه الري في جميع أنحاء شبكة الري بالتنقيط باستخدام قطارات سعة 3.0 لتر / ساعة، تم تطبيق ماء الري على ست ترددات: 50 75، 100 و125% من التبخر المرجعي. أوضحت النتائج أن خصائص الأوراق (أي ارتفاع النبات والوزن الرطب للنبات، والوزن الجاف للنبات، والمادة الجافة للنبتة ومحتوى الماء الخضر) قد تأثرت معنوياً بنظام الري، حيث أدت زيادة كمية مياه الري إلى زيادة النمو الخضري. أشارت البيانات أيضًا بوضوح إلى أن زيادة الري أدت إلى زيادة كبيرة في خصائص الأوراق (الكلوروفيل الكلي ، ومحتوى ماء الأوراق) ، أي محتوى الماء الحر (FWC) ، ومحتوى الماء المرتبط (BWC) ، وإجمالي محتوى الماء (TWC) ، ومحتوى الماء النسبي (RWC)، زاد محتوى برولين الأوراق بشكل كبير مع زيادة الإجهاد المائي (تقليل كمية مياه الري)، أدت زيادة كمية مياه الري إلى زيادة محتوى مغذيات الأوراق أدى الري بنسبة 100% من ET0 إلى تحسين الخصائص الفيزيائية والكيميائية لدرنات البطاطس، تم تحقيق أقصى إنتاجية للدرنات عند 100% من معاملة (32.36) ET0 طن / هكتار) بالإضافة إلى ذلك تم تحقيق أقصى كفاءة في استخدام المياه عند نفس مستوى مياه الري (17.249 كجم درنات / م 3) من المياه المطبقة تم استخراج معظم رطوبة التربة من طبقة التربة العلوية 40 سم. تمت زيادة استخلاص الرطوبة معنويا مع زيادة كمية مياه الري، تراوح التوتر الأمثل لرطوبة التربة لمحصول البطاطس بين 0.25 و 0.35 بار أهم نتائج الدراسة الحالية هي توضيح الدور الهام لنظام الري مع نظام الري بالتنقيط في تحسين نمو البطاطس ومحصول الدرنات أيضا ، التوزيع الجيد للرطوبة بشكل عام على عمق منطقة الجذر ، والتي يمكن أن تعزز نمو النبات وإنتاجية محصول البطاطس، توصي الدراسة الحالية بنسبة 90% من(ET0 1238.3 متر مكعب من الماء المستخدم / الفدان) لتحقيق أعلى محصول من البطاطس وجودة الدرنات في نفس الظروف الحالية .

الكلمات المفتاحية: البطاطس، الري بالتنقيط، التبخر المرجعي، كفاءة استخدام المياه، رطوبة التربة الإجهاد المائي.

Introduction

Water is the most important factor in agriculture, especially in areas of limited water resources. Schedule irrigation is the main factor in improving irrigation and water use efficiencies. Water deficit can cause serious losses in most crops. Water stress has been shown to affect many plants physiological processes, for example, stomatal opening (Henson *et al.*, 1989), plant water use (Bradford and Hsiao, 1982), plant water potential (McCutchan and shackel, 1992), CO_2 assimilation (Robinson *et al.*, 1988), plant growth (Acevedo *et al.*, 1971 and Abdel-Nasser and EL-Shazly,2000), plant productivity (Bradford and Hsiao, 1982) and sugar accumulation, (Handa *et al.*, 1983). On the other hand, water logging can reduce photosynthesis (Childers and White, 1950), transpiration and stomatal conductance (Andersen *et al.*, 1984), shoot and root growth (Rom and Brown, 1979) and fruit yield (Olien, 1987 and Abdel-Nasser and EL-Shazly,2000). Thus, improving management of irrigation water may lead to substantial water saving and improvement of plant growth and productivity. One of the best approaches to achieve good water management program is estimating the response of crop to different irrigation regimes.

the most agriculture in Libya such as sandy soil, there is a critical balance between water requirements and water consumption, thus, water saving is becoming a decisive factor for agricultural expansion. So, irrigation should be manipulated to maximize potato production per unit of applied water. In such areas, demands for irrigation scheduling and determining the crop water requirements impose the need to study and measure water status in the continuous soil-plant-atmosphere system. Maximizing the potato production depends on timely available water, also water conservation practice, which enhance this availability to be useful.

Many irrigation experiments have shown that potato is relatively sensitive to moisture stress (Epstein and Grant, 1973; Phene and Sanders, 1976; Shalhevet et al., 1983; Hang and Miller, 1986; Marutani and Cruz, 1989; Shock et al., 1998; Opena and Porter, 1999; Porter et al., 1999; Fabeiro et al., 2001). Because it has a sparse root system and approximately 85% of the root length is concentrated in the upper 0.3 m soil layer (Opena and Porter, 1999). Water stress causes reduction of yield by reducing growth of crop canopy and biomass.

Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production. On the other hand, the intensity of the operation requires that the water supply be kept at the optimum level to maximum returns to the farmer. High-frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil matric potential in the rhizosphere to reduce plant water stress (Phene and Sanders, 1976).

However, the production of a high-quality potato crop requires the maintenance of relatively high soil moisture levels throughout the tuber growth period. Extended periods of drought can reduce total yield by reducing leaf area and photosynthetic rate. Short period of water stress can substantially increase the incidence of secondary growth, misshaped tubers, growth cracks and sugar end (Stark and Dwelle, 1989).

Therefore, the present investigation was carried out in order to study the effect of water stress under drip irrigation system on growth, yield, fruit quality, leaf total chlorophyll, free proline and mineral composition as well as water-use efficiency of potato crop.

Materials And Methods

The present study was conducted at – Zahra area during 2020/2021 growing season of potato crop. The texture of the experimental site was sandy. Some of its physical and chemical properties were determined before cultivation according to Klute (1986) and Carter (1993). The determinations are presented in Table (1).

Table (1) Soil analysis of experimental site for growing potato crop during 2020/2021growing season

Parameters	**Soil depth, cm**	
	0-30	**30-60**
Particle-size distribution, %		
Sand	88.0	86.1
Silt	8.7	9.3
Clay	3.3	4.6
Textural class	Sand	Sand
Saturation water content, cm^3/cm3	0.382	0.391
Field capacity cm^3, cm^3	0.211	0.215
Permanent wilting point, cm^3/cm^3	0.055	0.054
Available water, cm^3/cm^3	0.156	0.161
Bulk density Mg/m^3	1.638	1.649
Saturated hydraulic Conductivity, cm/day	224.0	217.3
Organic matter, %	0.45	0.41
Calcium carbonates, %	4.1	3.2
pH	7.6	7.8
EC (1: 1 soil: water extract), dS/m	1.25	1.10
Soluble Cations, Cmole(+)/Kg soil		
Ca2+	4.89	3.41
Mg^{2+}	2.56	1.92
Na^+	6.74	5.25
K^+	0.73	0.48
Soluble Anions, Cmole(-)/Kg soil		
$CO^{=}_3$	-	-
HCO^-_3	2.00	1.73
Cl^-	5.04	3.50
$SO_4^{=}$	7.37	5.63
Available nutrients, ppm		
N	29.3	27.4
P	6.7	6.3
K	75.1	60.6
Fe	3.2	2.9

Imported potato tuber seeds (*Solanum tuberosum*, L.) of Spunta were used in the present study. Planting was done on 2^{ed} of October 2001, in wet soil. The potato seeds were planted at 0.25 m apart in the row, in 0.75 m width and 40.0 m length rows.

Fertilization:

Fertilization was done by preparing a nutrient solution contains all essential nutrients for potato. The nutrients were supplied with irrigation water (fertigation system). The concentrations of all essential elements in irrigation water are presented in Table (2), The fertigation was applied during the growing period two times weekly.

Table (2). Concentration and sources of nutrients used for preparing the nutrient solutions used for potato fertigation

Element	Concentration (mg/L)	Sources
NO_3-N	120	Calcium Nitrates
NH_4-N	30	Ammonium Sulphate
P	70	Calcium super phosphates
K	280	Potassium Sulphate
Ca	140	Calcium Nitrates
Mg	24	Magnesium Sulphate
Fe	5.00	Fe -EDTA
Mn	0.60	Mn -EDTA
Cu	0.15	Cu -EDTA
Zn	0.25	Zn-EDTA
Mo	0.05	Ammonium Molybdate
B	0.50	Boric Acid

Irrigation regimes

Irrigation water was supplied throughout a drip irrigation network (Karmeli and Killer, 1975) using drippers of 4.0 L/hr capacity. The irrigation regimes were:

1. Irrigation at 50% of reference evapotranspiration.
2. Irrigation at 75% of reference evapotranspiration.
3 Irrigation at 100% of reference evapotranspiration.
4. Irrigation at 125% of reference evapotranspiration.

The irrigation requirement was computed according to the following equation:

$$\text{IRg} = \frac{IRn}{E_a\ (1 - \text{LR})}$$

where:
IRg is the crop evapotranspiration, mm/day
IRn is the water consumptive use under drip irrigation system, mm/day
E_a is the efficiency of irrigation system (assumed as 90 % for drip irrigation system).
LR is the Leaching Requirements required for salt leaching (assumed as 14 %).

and

$$\text{IRn} = K_r \times K_c \times ET_p$$

K_r is the reduction factor that reflects the percent of soil covering by plant foliage. K_r can be calculated by the equation described in (Karmeli and Keller, 1975):

$$K_r = GC + 0.5\ (1\text{-}GC) \leq 1$$

Where,
GC is the ground cover fraction (the plant canopy area divided by soil area occupied by one plant). We can assume that GC = 0.60.
Gc is the crop coefficient ranging from 0.40 to 1.15 for potato crop (Allen *et al.*,1998).
ET_0 is the reference evapotranspiration calculated with FAO Penman- Monteith equation (Allen *et al*., 1998) expressed as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$

Where,

ET0	Potential evapotranspiration, mm day^{-1}
Rn	Net radiation at the crop surface, MJ m-2 day^{-1},
G	Soil heat flux density, MJ m-2 day^{-1}, Generally very small and assumed to be zero).
T	Mean daily air temperature at 2.0 m height, °C,
U2	Wind speed at 2 m height, m s^{-1} ,
e_s	Saturation vapor pressure at 1.5 to 2.5-m height, kPa,
e_a	Actual vapor pressure at 1.5 to 2.5-m height, kPa,
e_s- e_a	Saturation vapor pressure deficit, Kpa,
Δ	Slope of vapor pressure curve, kPa°C^{-1},
γ	Psychrometric constant, kPa°C^{-1}

The climatic data were collected from the AL= Zahra Meteorology Station near by the experiment location. Soil moisture tension was monitored for each treatment at 30 cm depth during the growing season.

The irrigation treatments were started at 2 October 2019 and lasted up to February 5, 2020, ten days before harvesting (19^{th} of February, 2020). The treatments were arranged in randomized complete block design with four replications (the replication is represented by one row, 0.75 m width and 40.0 m length with area of 30.0 m^2).
After 80 days from planting, plant samples were collected from each treatment (15 plants of each replication) to determine the vegetative measurements i.e., plant height and foliage fresh and dry weights. Also, foliage dry matter was calculated.
Leaf samples were collected from each treatment (10 plants for each replication). Each leaf sample was divided into two portions. In the first portion, leaves were washed with tap water, distilled water, air-dried then oven dried at 65C^o to a constant weight. The dried samples were ground and then digested with concentrated sulfuric-acid + 30% hydrogen peroxide according to the method of Wolf (1982). Total N was determined by micro-Kjeldahl method (Jackson, 1973). Total phosphorus was determined according to the method of Murphy and Riley (1962). Total potassium was determined by Flame Photometer (Jackson, 1973). In the other portion of each leaf sample (fresh leaf material), total chlorophyll content was determined according to the method of Moran and Porath (1980). Total water content (TWC) and relative water content (RWC) were determined by the method of Weatherly (1950 and 1951). Free water content (FWC) and bound water content (BWC) were determined according to Abdel-Rasoul *et al.* (1987). Leaf free proline content was determined as described by Bates *et al.* (1973).
At harvesting time, tubers yield and tuber characteristics were determined as average of 10 random plants i.e., No. of tubers per plant, tubers yield per plant, average tuber weight and no. of tuber available for export. Physical and chemical characteristics of potato tubers were determined, i.e., tuber dry matter content, ash content, tuber length, tuber diameter and specific gravity (by dividing the tuber weight by its volume). Grading index was calculated by grading the tubers yield of 10 hills into 3 grads according to the tuber diameter; I (<30 mm); II (30-60 mm) and III (> 60 mm) as reported by EL-Gamal (1980):
The collected data were subjected to analysis of variance according to Steel and Torrie (1982). Correlation and regression were carried out according to Draper and Smith (1982) using statistical package of Microsoft EXCEL software.

Results And Discussion:
1. Foliage characteristics:

Foliage characteristics (i.e., plant height, shoot fresh weight, shoot dry weight, shoot and dry matter) as affected by irrigation regime are presented in Table (3). Irrigation regimes significantly affected the foliage characteristics (Table, 3).

Increasing soil water at irrigation resulted in significant increases in vegetative growth. The highest values were attained at the high level of irrigation (100% of ET_0).

The reduction of vegetative growth as a result of decreasing amount of irrigation (60% of ET0) may be due to the major effect of water stress in decreasing the water uptake by root system as a result of decreasing root function (Rowe and Bearsell,1973). The present results are in accordance of the previous results of Abdel-Nasser (1991) and Abdel-Nasser and EL-Shazly(2000).

Table (3). Foliage characteristics of potato crop as affected by irrigation regime

Irrigation regime	Plant height (cm)	Shoot fresh weight (g/plant)	Root fresh weight (g/plant)	Shoot dry weight (g/plant)	Shoot dry matter (%)
0.50 ET_0	28.8	231.42	28.41	25.32	10.94
0.75ET_0	31.3	241.25	30.71	28.48	11.81
1.00 ET_0	37.2	256.44	33.45	32.12	12.53
1.25 ET_0	38.5	264.26	34.72	34.01	12.87
L.S.D. (0.05)	1.72	2.83	2.26	2.69	1.22

2. Leaf characteristics

Total chlorophyll content of potato leaves as affected by irrigation regimes is presented in Table (4). The data clearly indicate that increasing amount of irrigation water significantly increase the total leaf content of chlorophyll. Such increase may be due to improve the plant growth as a result of more water and nutrients uptakes, such as N, K, Mg and Fe. Such elements have close association in chlorophyll biosynthesis (Hall and Rao, 1996). Also, it may be attributed for increasing photosynthesis rate as a result of more absorption of available nutrients, which cause an increase in growth and photosynthesis efficiency.

This result is true because of by increasing water stress, the plant has less ability to absorb water. Thus, the nutrients uptake decreased. Also, such reduction in chlorophyll content may be attributed to the role of water as a substrate for all vital processes in plant tissue especially in chlorophyll formation (Abdel-Nasser and El-Shazly, 2000 and Abdel-Nasser and Hussein, 2001).

Data presented in Table (4) indicate significant effects of irrigation regime in increasing the leaf water contents i.e., free water content (FWC), bound water content (BWC), total water content (TWC), and relative water content (RWC). This result may be attributed to more water absorption by potato plants as a result of more vegetative growth and more nutrients uptake. The less leaf water contents under water stress conditions (less amount of irrigation water at 60% of ET_0) can be explained on the fact that under high soil moisture tension, the moisture becomes less available to plant absorption, thus the leaf water content decreased (Werner, 1954, Slatyer, 1969, Epstein and Grant, 1973 and Abd-Allah, 1996). The same trend was noticed with specific leaf area, in which it increased with increasing amount of irrigation water. This result may be attributed to the role of water in increasing the plant growth.

It is evident from the data in Table (4) that leaf proline content substantially increased with increasing water stress (decreasing irrigation I.e., 60% of ET_0). Moreover, there were significant differences between irrigation treatments. Such results may be due to the role of proline in regulating water transport in plant tissues (Aloni and Rosenshtein, 1984 and Srinivasa Rao, 1986). Similar results were obtained by Good and Zaplachinski (1994), they found a marked increase in proline content of drought-stressed leaves. Also, the data of Abdel-Nasser and El-Shazly (2000) confirmed the present result. The results of many studies suggest that the relative accumulation of proline in response to water stress is likely to vary between plant species (Good and Zaplachinski, 1994, Turner and Stewart, 1988 and Abdel-Nasser and El-Shazly, 2000). They found that a marked increase in proline content for water-stressed leaves.

The data in Table (4) generally indicated that increasing amount of irrigation water increased leaf nutrients content (N, P and K,). The marked decrease of leaf nutrients content was found at higher water stress (60% of ET_0 treatment). Such a reduction may be explained on the basis that under water stress, the soil moisture became unavailable to root uptake, thereby, decreased nutrient uptake by plants (Mengel and Kirkby, 1987), in addition to general weakness of plant conditions as a result of water stress that reflected on plant absorption and translocation (Abdel-Nasser and EL-Shazly, 2000).

3. Tuber physical characteristics

Data presented in Table (5) show the effects of irrigation regimes on potato tuber physical characteristics. Tuber physical characteristics, such as No. of tubers per plant, average tuber weight, tubers available to export, grading index by number and by weight, tuber length, tuber diameter, tuber shape index and tuber specific gravity, significantly affected by irrigation regimes (Table, 5). The present results are in accordance with the results of Abd-Allah (1996). The maximum values were attained with 100% of ET0 treatments and a reduction was noticed with higher irrigation water (110% of ET_0). The reduction in tuber physical characteristic at highest water application may be due to the role of excessive water in decreasing some metabolic processes of root system.

4. Tuber chemical characteristics:

Data presented in Table (6) show the effects of irrigation regimes on potato tuber chemical characteristics. Tuber chemical characteristics such as dry matter content, ash content, starch content, reducing sugars and protein content significantly increased by increasing the amount of irrigation water. In addition, highest irrigation treatment (110% of ET_0) decreased the chemical characteristic of tubers. The same results were reported by Abd-Allah (1996).

Table (4). Leaf total chlorophyll, water contents and nutrients content of potato crop as affected by irrigation regime:

Irrigation regime	Leaf Total chlorophyll (mg/100g)	Total water content (%)	Specific leaf weight (g/m^2)	Proline content (mg/g)	Leaf nutrients content, %		
					N	P	K
0.50 ET_0	262	78.54	28.21	6.99	2.12	0.38	2.75
0.75ET_0	282	81.82	34.68	5.80	2.25	0.49	2.94
1.00 ET_0	308	84.82	37.42	3.77	2.38	0.60	3.17
1.25 ET_0	312	85.72	38.78	3.75	2.42	0.63	3.21
L.S.D. (0.05)	11.72	1.64	1.32	0.76	0.09	0.12	0.15

Table (5). Tuber physical characteristics of potato crop as affected by irrigation regime.

Irrigation regime	No.of tubers/plant	Average Tuber weight (g)	Tuber length (cm)	Tuber diameter (cm)	Tuber shape index	Specific gravity
0.50 ET_0	4.80	130.01	8.00	5.00	1.600	1.0684
0.75ET_0	5.70	136.22	8.60	5.40	1.593	1.0784
1.00 ET_0	6.70	142.32	8.90	5.60	1.589	1.0882
1.25 ET_0	6.30	138.85	8.92	5.70	1.623	1.0782
L.S.D. (0.05)	0.28	3.54	0.38	0.42	0.071	0.0119

Table (6). Tuber chemical composition of potato crop as affected by irrigation regime.

Irrigation regime	Dry matter content (%)	Ash content (%)	Starch content (%)	Tuber nutrients content, %		
				N	P	K
0.50ET_0	18.82	5.11	14.51	1.14	0.17	2.16
0.75ET_0	19.41	5.30	14.78	1.16	0.21	2.25
1.00 ET_0	20.13	5.41	15.22	1.18	0.22	2.27
1.25ET_0	20.83	5.50	14.55	1.18	0.22	2.26
L.S.D. (0.05)	0.62	0.18	0.40	0.03	0.03	0.10

The effects of irrigation regimes on tuber nutrients content are also shown in Table (6). Tuber nutrients content significantly increased because of increasing the amount of irrigation water.

5. Tuber's yield, Water-Use Efficiency and production function

The calculated water use according to the irrigation regimes were 2066, 4132 and 8264 m^3/fed/season corresponding to 15, 30 and 60 minutes per day.

Table (7) shows the effect of irrigation regimes on potato tubers yield and water-use efficiency. Increasing amounts of Irrigation significantly improved tubers yield. The highest values of tubers yield were attained with 90% of ET_0 (21.359 ton /fed.).

The water-use efficiency (WUE) was calculated according to the following equation:

$$WUE\left(Kg\ tubers/m^3\ applied\ water\right)=\frac{Tubers\ yield\left(Kg/\ fed.\right)}{Applied\ water\left(m^3/\ fed./season\right)}$$

Table (7) Potato tubers yield, water use efficiency and soil moisture extraction at soil depths affected by irrigation regime.

Irrigation regime	Tuber Yield (g/plant)	Gross yield (Ton/ha)	Water use (m^3/ha)	WUE (Kg/m^3)	Soil moisture extraction, %		
					0-20 cm	20-40 cm	40-60 cm
0.50 ET_0	624.05	13.074	270	15.838	56.32	28.32	15.36
0.75ET_0	776.45	18.301	395	16.627	66.52	22.58	10.90
1.00 ET_0	953.54	21.359	520	17.249	71.82	20.82	7.36
1.25 ET_0	874.76	19.199	645	12.686	78.82	19.48	6.70
L.S.D. (0.05)	51.93	1.25	57.81	1.04	3.55	1.98	4.58

Concerning the water saving concept, the values of WUE as affected by irrigation regimes are presented in Table (7). The results indicated that the best tuber water use efficiency was attained with 90% of ET_0. The WUE was 17.249 Kg tubers/m^3 applied water. The higher and lower amounts of irrigation water tend to decrease the WUE.

In the present study, the production function was done between the total amount of applied irrigation water vs. fresh tuber yield. Through non-linear regression analysis, a mathematical function was obtained that showed a highly significant determination factor (R^2=0.9448).

$$Y = 4 \times 10^{-5} + 0.0793\ X - 26.767$$

Where,

Y is the tuber yield, tones/fed.

X is the water applied, m^3/fed

Figure (1) shows the relationship between the total amount of applied irrigation water and total fresh tuber yield. The production function showed that tuber yield near the 90% of ET_0 (1325,6 m^3/fed) was close to the theoretical maximum tuber yield (20.56 ton/fed.), then the water use efficiency is 15.51 kg tuber/m^3 of applied irrigation water.

6. Soil moisture extraction pattern and soil moisture tension:

The results illustrated in Table (7) showed that most of the soil moisture was extracted from the top 40 cm soil layer for all treatments, moreover, the soil moisture extraction from the top 40 cm soil layer was increased significantly as the amount of irrigation water increased.

The high percentage of moisture extraction from the top 40 cm soil layer might be due to increase evaporation loss from the surface layer against the atmospheric conditions (Ritchie, 1971 and Hsiao, 1973). The moisture extraction from the deeper layer was due to less root ramification.

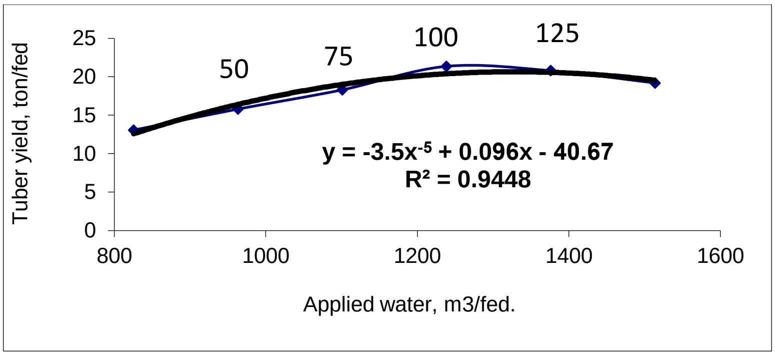

Figure (1) Tuber water-production function.

The increasing moisture extraction under high irrigation frequency (%100 of ET_0) may be due to that water was more available for evaporation and plant uptake, consequently increased the moisture contribution (Gardner, 1960). Under low water application (60% of ET_0 treatment), moisture extraction was increased from the deeper layer. Such results could be interpreted on the basis that, as soil moisture tension increased (less applied water), the root penetration increased to get more moisture from deeper layers, Sen *et al.* (1984). Dargan and Ram (1969) reported that moisture depletion percentage decreased with increasing the depth of root zone. The results of Abdel-Nasser and Hussein (2001) and Abdel-Nasser and EL-Shazly (2000) confirmed the present results.

The soil moisture tensions were recorded during the growing season at 30 cm depth. Soil moisture tension of 50% ET_0 treatment was ranged between 0.74 and 0.82 bar, while the soil moisture tension for 100%ET_0 treatment was ranged between 0.11 and 0.19 bar. These values confirmed the water stress at low irrigation regime. The optimum soil moisture tension for potato was between 0.26 and 0.39 bar corresponding to 100% ET_0 treatment.

The most important outcomes from the present study are clarifying the important role of irrigation regime with drip irrigation system in improving the potato growth and tuber yield. Also, good distribution of moisture overall the root zone depth, that can enhance the plant growth and yield of potato crop. The present study recommends a 90% of ET0 (1238.3 m^3 of applied water/fed) to achieve highest potato yield and tuber quality under the present conditions.

Conclusion

The results obtained from the research indicated that programming irrigation and fertilization of nitrogen fertilizer means that it is possible to obtain a productivity close to ideal, as there is a significant interaction between the levels of irrigation and fertilizer in terms of productivity, vegetative growth, physiological or morphological characteristics, as well as nutrients in the plant leaves. The results also confirmed the importance of irrigation and fertilization. On the process of photosynthesis and the concentration of proline acid, it was noted that the greater the amount of added water, the higher levels of fertilizer are not compatible with low levels of irrigation. This is a topic that needs more research, by monitoring irrigation and fertilizer in the soil at depths of the soil and for similar periods of time, while linking this to the concentration of fertilizer in the leaves and measuring the water potential. In plants, as the researchers believe, the issue of irrigation and fertilizer programming requires more research, and perhaps digital agriculture, remote sensing, and the Internet of everything may be an effective means of studying this topic, as well as using humidifying digital devices and programs.

This topic is intended for precise monitoring, especially in the sandy soils, hot climate, and climatic variability of the Mediterranean region, especially in the spring and fall seasons for this region, to achieve optimal and appropriate irrigation and nitrogen fertilizer.

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