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Effect of Water Deficiency in Different Stages of Potato (*Solanum tuberosum* L.) Growth

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Abstract: The experiment was conducted to assess the sensitivity of potato yield to different irrigation levels at different growth stages. Irrigation levels were determined as percentages (WI 100% as readily available water to the crop (RAW)), and for the rest of the treatments (WII 75%, WIII 50%), as they were applied separately to all four stages of crop growth i.e., vegetative (SI), tuber initiation (SII), tuber bulking SIII, and tuber maturation (SIV). The design of complete random sectors was adopted to perform the experiments. The results revealed that all the studied parameters: plant height (cm), vegetation plant weight (g), number of tubers per plant, tuber weight (g), tuber yield (ton/ha), and crop water productivity (kg/m^3) varied among irrigation water levels at different stages of growth. It was found that the two stages, SII and SIII in potato crops, were more sensitive to deficit irrigation compared to other stages. According to the obtained results, in the case of water abundance conditions, the treatment WII SI can be applied to obtain the highest water crop productivity. In conditions of water scarcity, it becomes necessary to apply the treatment WIII SIII to obtain the highest crop water productivity.

العجز المائي عند مراحل نمو مختلفة للبطاطس (*Solanum tuberosum* L)

الكلمات المفتاحية :
البطاطس،
العجز المائي،
الإجهاد المائي،
كفاءة استخدام المياه،
الانتاجية المائية المحصولية.

المستخلص : تهدف هذه الدراسة إلى تحديد تأثير العجز المائي عند مراحل النمو المختلفة علي إنتاجية محصول البطاطس. تم تحديد معاملات الري كنسب مئوية (WI 100%) كمياه متاحة للمحصول بسهولة (RAW)، ولبقية المعاملات (WII 75%، WIII 50%)، حيث تم تطبيقها علي جميع مراحل نمو المحصول الأربعة: النمو الخضري (SI) تكوين الدرنات(SII) ، ملء الدرنات (SIII) و نضج الدرنات (SIV) كل على حدا، وضمن تصميم القطاعات العشوائية الكاملة. أظهرت نتائج التجربة الحقلية المعاملات المختلفة التي تم دراستها والتي اشتملت على ارتفاع النبات(سم)، وزن المجموع الخضري (جم)، عدد الدرنات لكل نبات، وزن الدرنات (جم)، الانتاجية (طن/هكتار)، والانتاجية المائية المحصولية(كجم/م^3) كان بينها اختلافات متباينة بين مستويات مياه الري في مراحل النمو المختلفة. وجد أن المرحلتين الثانية (SII) و الثالثة (SII) كانتا الأكثر حساسية للري الناقص مقارنة بالمراحل الأخرى. وفقا للنتائج المتحصل عليها، وفي حال ظروف الوفرة المائية، فإنه بالإمكان تطبيق المعاملة WII SI للحصول على أعلى انتاجية مائية. أما عند ظروف ندرة المياه، يصبح من الضروري تطبيق المعاملة WIII SIII للحصول على أعلى انتاجية مائية.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth crop produced worldwide after rice, wheat, and corn, with a total global production of 365 million tons in 2012 and a cultivated area of 18.6 million hec tares (FAO, 2014). There has been a dramatic increase in potato production and demand in

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Asia, Africa, and Latin America, where the yield rose from less than 30 million tons in the early 1960s to more than 381 million tons in 2014 (PotatoPro, 2014). Potato is a water-stress-sensitive crop. Potato plants are more productive and produce higher tuber quality when watered precisely using soil water tension than if they are under or over irrigated (Hashem et al., 2016; Rosen et al., 2014). Also, potato is sensitive to deficit irrigation throughout various growth stages, especially in tuber formation up to harvest (Badr et al., 2022; Bahramloo & Nasseri, 2009; Shock, 2004; Thornton, 2002) found the sensitivity of potatoes to water stress was more remarkable when water was applied at individual growth stages than at different severities of water stress. Potato development is differentiated into four growth stages, namely: sprout growth, tuber initiation, tuber bulking, and tuber maturation (Struik & Wiersema, 1999). The period of these growth stages is controlled by the environmental and management factors related to locations as well as the plant variety (Doorenbos & Pruitt, 1977; Warsito & Van de Fliert, 2006). All these developmental stages can be identified on early, mid, and late cultivars and are like those suggested by (Van Loon, 1981).

The vegetative growth stage begins from the planting date and extends to the stolon's formation. The duration of the vegetative growth stage ranges from 30 to 70 days and depends on varieties, cultural practices, and environmental conditions (Patil & Sundaresha, 2016). The tuber initiation stage takes around 20 to 30 days (Cowan, 1986). According to (Kang et al., 2004), the tuberization stage begins when the stolon tip starts to swell and the tuber begins to develop, which lasts from 10 to 14 days. Although additional stolons may continue to form during later stages of plant growth, marketable tubers are formed during this stage. The tuber bulking growth stage extends from the time when tubers are about one-half inch in diameter to the beginning of canopy senescence with a duration of 60 to 120 days. This wide variation is deeply dependent upon variety, nutrient availability, and environmental conditions (Kang et al., 2004). As indicated by the International Potato Center (CIP, 1984), potato tuber swelling has a period of 60 to more than 120 days, contingent upon the length of the developing season and presence of pathogens. Tuber maturation begins with canopy senescence. The growth of the tuber shows a lower rate during maturation than during the tuber bulking stage (Ojala et al., 1990). The tuber bulking period is the time between tuber initiation and duration of foliage, while tuber bulking growth can be depicted by the slant of a straight bend, with the expansion in tuber mass after some time (Ojala et al., 1990). Tubers' weight may reach up to 300 g each. Generally, they differ in size and shape (FAO, 2008).

Water stress during the vegetative growth stage reduces leaf area, root expansion, and plant height and delays canopy development. There is an agreement among agricultural specialists including (Braue et al., 1983; Ojala et al., 1990 ; Kempen,2012), upon the fact that water stress during the maturation stage would be accompanied by a decline in photosynthesis rate, regression in the tuber development rate, and the vine dieback. The impact of water deficit through the different growth stages should be known before implementing a stress irrigation program. It is necessary to know crop yield responses to water stress (Kirda & Kanber, 1999) at different stages.

This study aimed to assess the sensitivity of potato yield to different irrigation levels at different growth stages in the Jordan Valley.

MATERIALS AND METHODS

Experimental site and weather conditions: The study was carried out at the Agricultural Experimental Station of Jordan University in the Jordan Valley. The Station is located at 32°50' N and 35°34'E. The altitude is 370 m below sea level. Climate is warm in winter and hot in summer. The average minimum temperature is 18.5℃ and maximum temperature is 30℃, with annual rainfall ranging from 100 to 150 mm.

Land preparation and soil data collectio: The field was tilled by disc plough to approximately 30 cm depth. The field was divided into plots and then it was completely flooded by water. For determining the required physical and chemical characteristics, three composite samples (2kg) were collected from each soil layer (0-20, 20-40, and 40 – 60 cm). According to (Ababsa, 2013), the soil of the experimental site was classified as Hyperthermic, Typic Torriorfluents. Different soil properties were measured including field capacity and permanent wilting point which was determined using ceramic plate (Cassel & Nielsen, 1986). The bulk density of soil was determined by the core method with a soil volume of 63 cm^3 (Blake & Hartge, 1986). The soil texture was performed using the pipette method (Gee et al., 1986). Calcium carbonate in soil was estimated by the sodium hydroxide method (Nelson, 1982). Electrical conductivity and pH of the soil were determined in (1:1) soil extract (McLean, 1982). Phosphorus was determined according to (Olsen, 1982). The Kjeldahl digestion-distillation method was used to estimate the nitrogen content in the soil (Bremner & Mulvaney, 1982). Potassium was extracted by acetic acid and measured by a flame photometer system (Knudsen et al., 1983). Some physical and chemical properties of the soil are presented for the different soil layers in Table (1).

Table (1). Some physical and chemical properties of the soil.

Soil depth (cm)	0 -20	20-40	40-60
Texture	Sandy clay loam	Sandy clay loam	Sandy clay loam
Bulk density (gm/cm^3)	1.43	1.47	1.42
FC (cm^3/cm^3)	0.293	0.285	0.298
PWP (cm^3/cm^3)	0.139	0.129	0.136
EC (dS/m)	0.467	0.627	0.473
pH	7.4	8.01	8.1
$CaCO_3$ (%)	24.9	25.6	24.7
Total N (%)	0.45	0.51	0.49
P (ppm)	60.7	40.6	42
K (ppm)	62.4	56.1	52.1

Growth stages: The length of the growing stages of potatoes depends on planting date, soil temperature, climate, location, and other environmental factors (Doorenbos & Pruitt, 1977; Lisinska & Leszczynski, 1989) In this study, the potato (*Solanum tuberosum* L.) cultivar˝Spunta‶was grown under three different irrigation treatments, which were initiated at each growth stage to the end of the growing season. The length of potato growing stages was determined based on visual observations and recognizing their characteristics as mentioned by Johnson (2008) as follows:

Stage 1(SI): Vegetative growth. It extended up to 48 days after planting tubers (DAP).

Stolon's formation started when plant height was17 cm;

Stage 2 (SII): Tuber initiation. It took 20 days after stage I and depended on stolon's devel opment. The swelling of tubers reached to less than one inch.

Stage 3 (SIII): Tuber bulking. It took 33 days after stage II and tubers were about one-half of its final of this stage.

Stage 4 (SIV): Tuber maturation. It took 18 days after stage III depending on the chlorophyll percentage in leaves. Table (2) depicts the cauterization of potato growth stages.

Experimental Design: The experiment consisted of 12 treatments that resulted from the combination of three different irrigation treatments (factor 1) and four growth stages (factor 2) with three replications using a factorial arrangement in Randomized Complete Block Design (RCBD). The size of each unit plot was 8 m in length with a width of 5 m; plants were spaced at 0.40 m within rows and 0.80 m between rows. Each plot contained 100 plants. Plots were separated by 2 m from each other within the plot and 3 m between replicates. Tubers were manually planted on Dec 20th 2015 with a density of 3.125 plant/m^2.

Table (2). Characterization of plant growth stages

Growth stages of potato	Stages(S)	Date	Number of days
Planting		20/12/2015	0
Vegetative	SI	05/02/2016	48
Tuber initiation	SII	25/02/2016	20
Tuber bulking	SIII	29/03/2016	33
Tuber maturation	SIV	16/04/2016	18
Total number of days	119		

Plant harvesting: The potato tubers were harvested on 16th April 2016 and the harvested plot`s size was 11.52 m^2 (three rows at the center of each plot (4.80 m× 2.40 m). At the physiological maturity stage, vegetation weight, tubers weight, tuber number, and potato yield per treatment and hectare were measured. Mean measured values were taken per plant for tubers' weight and plant height.

Estimation of irrigation supply: The three irrigation treatments were 100, 75, and 50% of the readily available water (RAW). They were irrigated on the same dates with different durations for each treatment when the measured volumetric soil water content of 100% reaches the critical value. The management allowable depletion was taken as 40% of total available water. Soil water content was monitored in each plot using calibrated time domain reflectometer (TDR). The soil water content was measured for each 0.2 m soil layer before and after each irrigation using an access tube with a diameter of 5.5 cm holes. A drip irrigation system was used with one irrigation source line and drippers spaced 0.4 m with an average discharge of 4 Lh^{-1}.

The distribution efficiency of emitters was evaluated by the discharge of the three emitters per line and showed a flow difference of 9.5%. Detecting irrigation treatments were considered at the following four developmental stages. Table (3) depict the irrigation treatments and their details.

Fertilizer application: All treatments were supplied with the recommended amount of fertilizer (255 kg N (ammonium sulfate 21%) ha^{-1}, phosphorus 70 kg of P ha^{-1} (20- 20 -20-Trace elements), and 132 kg of K ha^{-1} (12 -12 -36 +total elements) through the irrigation water in all treatments. According to (Demelash, 2013), fertilizer requirements are 80 to 120 kg ha^{-1} N, 50 to 80 kg ha^{-1} P and 120 to 160 kg ha^{-1} K, depending on soil analysis and irrigated crop.

Table (3). Irrigation treatments and their details

Irrigation treatment	Details
WI	100% of RAW: Irrigation amount for all stages (SI, SII, SIII and SIV).
SIWII	75% of RAW at SI and 100% of RAW during SII, SIII and SIV.
SIWIII	50% of RAW at SI and 100% of RAW during SII, SIII and SIV.
SIIWII	75% of RAW at SII and 100% of RAW during SI, SIII and SIV.
SIIWIII	50% of RAW at SII and 100% % of RAW during SI, SIII and SIV.
SIIIWII	75% of RAW at SIII and 100% of RAW during SI, SII and SIV.
SIIIWIII	50% of RAW at SIII and 100% of RAW during, SI, SII and SIV
SIVWII	75% of RAW at SIV and 100% of RAW during SI, SII and SIII.
SIVWIII	50% of RAW at SIV and 100% % of RAW during SI, SII and SIII.

Water management: Irrigation water was managed in relation to the soil moisture level. The first treatment (100%) was effected by applying all the moisture extracted from effective root zoon (ERZ) when the depletion percentage (Dp) reaches 40% of RAW. The volumetric soil water content was performed by using TDR for the different layers of ERZ at different depths i.e., 0-20, 20-40, and 40-60 cm. The second treatment was planned for 75 % of full irrigation, and the third level by the application of 50% only. Through this low-discharge emitters irrigation system there will be no runoff and consequently, this term had been neglected in the water balance equation. Deep percolation has been minimized through the low rate of application and checked by the measurement of the moisture content below the root zone (60-90 cm) before planting and after harvest. Irrigation scheduling was based on the soil moisture balance measurement, including the amount of each application and timing (Gheysari et al., 2009).

$$NRD = \sum_{i=0}^{n}(\theta_{FC} - \theta_{sb})D_i \qquad (1)$$

Where, NRD refers to the net irrigation depth (mm) which was applied at irrigation time. θ_{FC} refers to soil water content at field capacity (cm^3cm^{-3}), D_i refers to the thickness of each soil layer (mm), θ_{sb} refers to soil water content before irrigation time (cm^3cm^{-3}) at 40% of RAW.

Therefore, consumed water (CW) was calculated by applying the water balance equation to the (ERZ) 60 cm.

$$ET = I - (R + D_p) \pm \Delta\theta \qquad (2)$$

Where, ET refers to evapotranspiration (mm), I refers to the amount of applied irrigation water (mm), R refers to the surface runoff (mm) which is negligible, Dp refers to the deep percolation (mm), and $\Delta\theta$ refers to the change in the soil water storage prior to planting and after harvesting of the soil profile above 60 cm depth (mm) (Watson & Burnett, 1995). (Pereira & Shock, 2006) showed that ET of potato crop in duration 120 to 150 days was 500 to 700 mm, depending on atmosphere conditions.

Crop water productivity and water use efficiency: The concepts of water use efficiency (WUE) and water productivity of crops are important indicators for evaluating the water consumption of crops (Ekhmaj & Almuntaser, 2016). The term water use efficiency is used in different ways by agronomists and physiologists depending upon the emphasis that one wishes to place on certain aspects of the problem. Agronomists define this term as crop yield per unit of water use (Sinclair et al., 1984). The total water lost by evapotranspiration and transpiration is often used for this purpose. As 99% of the water consumed by crops in the field is transpired from crop leaves and evaporated from the soil surface, water use efficiency in effect, is the reciprocal of evapotranspiration. Physiologists define the WUE concept in terms of the process of photosynthesis, expressing it in milligrams of CO_2 per gram of water (Kramer, 2012). Water productivity (WP) can be defined as the ratio of the economic yield of a crop to the total water supply diverted to irrigate the crop (Alghariani, 2006) Both diverted and consumed water include the sum of the total water flow in addition to the net flow and water depleted by the crop (Molden, 1997; Molden & Sakthivadivel, 1999). Thus, in agricultural systems, and in terms of water consumed by the crop, crop water productivity is considered to be a measure of the output of that system. However, to reach the goal of determining the crop water productivity for the whole agricultural system, this must be done in time and space (Gichuki et al., 2006).

In this study, two indicators were adopted to assess water consumption, which are the water productivity of crops at the field level (WP) or the production yield per unit volume of irrigation water and water use efficiency (WUE). The following equations show the mathematical formulas for these indicators:

$$WP = \frac{Y}{I} \qquad (3)$$

$$WUE = \frac{Y}{ET_c} \qquad (4)$$

Where Y refers to potato yield for each treatment (kg/ha), (I) is applied irrigation water for each treatment (m^3/ha) and ET_c is potato evapotranspiration (m^3/ha)

Statistical analysis: Data collected from the field experiment was statistically analyzed using SAS program version 8. Analysis of variance (ANOVA) was used to estimate the significance of irrigation treatments and stages. Means showed significant differences were separated by the least significant difference (LSD) test at P<0.05.

RESULTS AND DISCUSSIONS

Water balance of the root zone: Initial, final, and the change of soil water depths within the root zone of potatoes during entire growth stages and water treatments are depicted in figure (1). It was found that the initial soil water depths (at the beginning of the experiment) were uniform within the root zone at 80 mm. The final soil water depths (at harvesting the crop) were between 58 mm (during the SIV with WIII) and 78 mm (during the SIII with WI). The changes in soil water depth were determined as a difference between initial soil water depths and final water depths. The changes in soil water depths were between 2 mm (during the SIII with WI) and 23 mm (during the SI with WI). The changes in soil water depths were used to determine the water balance of potato cultivation.

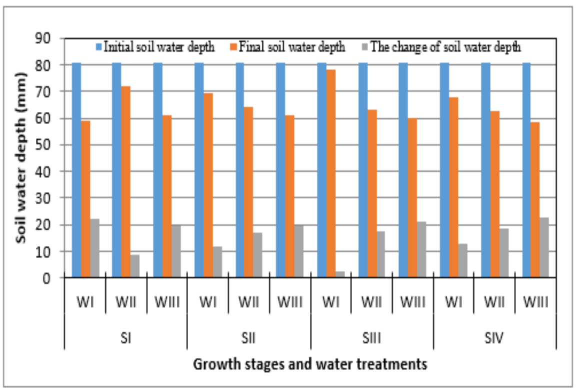

Figure (1). Potato crop evapotranspiration for the different treatments.

Table (4) shows the water balance for the different treatments. Essentially, the water supply was based on irrigation and soil water content since there was no precipitation occurring throughout the whole four growth stages. The deep percolation was noted to be in small amounts, and the runoff was ignored as no runoff was noticed. The maximum and the minimum of evapotranspiration were 711 and 561 mm, for SIWI and SIII WIII, respectively.

Deficient irrigation treatments led to a reduction in evapotranspiration at different rates according to the plant growth stages. It showed differences among irrigation treatments, as well. The maximum decrease in evapotranspiration, 8.1% and 18.8%, were noticed during tuber bulking stage in the second and third irrigation treatments, respectively. The reason for this, is that the quantities of irrigation water added to the full irrigation treatment were higher than the incomplete irrigation treatments, which led to an increase in the processes of transpiration by the plant and evaporation from the soil surface. In addition, it was also found that the highest evapotranspiration was at the vegetative growth stage, the tuber emergence stage, and tuber formation. However, these results are similar to the literature data (Onder et al., 2005; Sadiq, 2013).

Plant height: Results, as shown in Figure (2), explained that irrigation water during all growth stages has no significant effect between water levels, while there was a significant effect between stages under the significant level of (0.05). The average plant height tends to increase under the irrigation treatment of WII at the SI, at which the highest height of 51 cm was recorded. The deficit irrigation treatment of WIII gave the least average height at the SIV, recording 41 cm tall, and did not show any difference in all treatments of water at SII and SIII. It might be due to the fact that the crop encountered favorable soil moisture conditions, which enhanced the availability of nutrients essentially required for the enlargement and elongation of plant cells. However, as it was indicated by (Zrust, 1995), that plant height was initially water sensitive for plant height, with a 20% reduction rate for full irrigation treatment, which was consistent, as well, with (Kang et al., 2004; Kashyap & Panda, 2003).

Table: (4). Water balance for the different treatments.

Stage	Treatment	ET (mm)	I (mm)	P (mm)	R (mm) (mm)	Dp (mm)	±Δ θ(mm)
SI	WI	702	692	0	0	3	13
	WII	677	670	0	0	3	9
	WIII	662	648	0	0	6	20
SII	WI	701	692	0	0	3	12
	WII	665	651	0	0	3	17
	WIII	624	609	0	0	5	20
SIII	WI	691	692	0	0	3	2
	WII	635	619	0	0	2	18
	WIII	561	545	0	0	5	21
SIV	WI	702	692	0	0	3	13
	WII	681	665	0	0	2	18
	WIII	654	637	0	0	5	23

Vegetation plant weight: The results showed the significant effect of irrigation treatments on vegetation plant weight at growth stages of SII, SIII, and SIV. On the other, irrigation treatment in SI has no significant difference in the average weight of vegetation plants which reached 607, 600, and 595g, respectively, in irrigation treatment WII, WI, and WIII, as indicated in figure (3). SII showed no significant difference between WII and WIII, showing that the lowest weights of plants of 400 and 382 g were respectively related to irrigation treatments of WII and WIII.

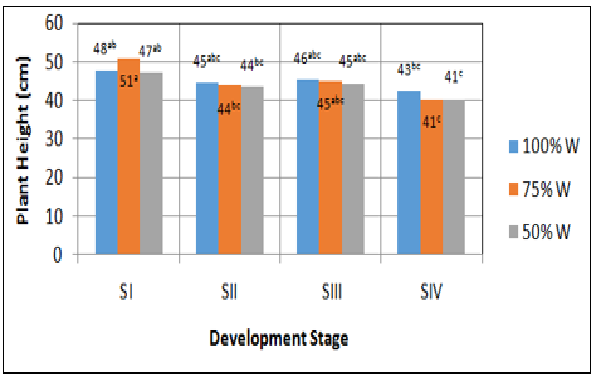

Figure (2). Effect of deficit irrigation treatments on the final heights of plant. LSD (P<0.05).

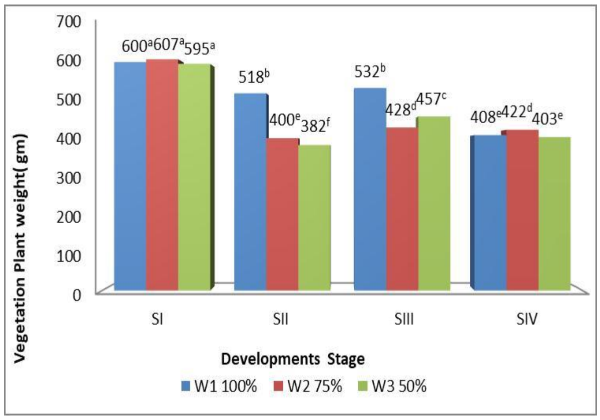

Figure (3). Effect of deficit irrigation on plant weight at growth stages. LSD (P<0.05).

Number of tubers per plant: The effect of deficit irrigation treatments on the average number of tubers is different during all growth stages (Figure 4). While the number of tubers showed a significant effect at SII, it was obvious that the greatest number of tubers was recorded at SI WII with 10 tubers per plant. At the SII WIII stage, the average number of tubers was six because the deficit irrigation met the critical stage of tubers formation showing a clear negative effect on both physiological activity and produced metabolites.

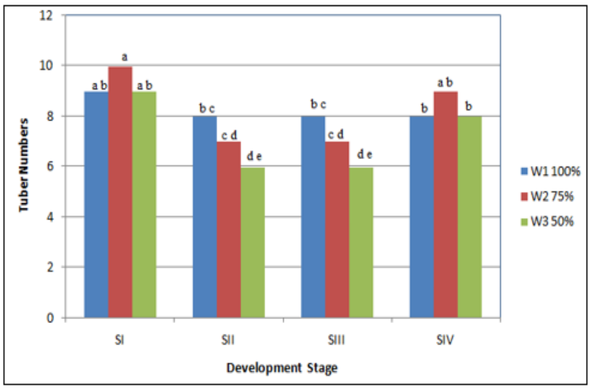

Figure (4). Effect of deficit irrigation treatments on the average tubers number per plant. LSD (P<0.05).

As indicated by (Zrust, 1995), that plant height was initially water sensitive for plant height, with a 20% reduction rate for full irrigation treatment, which was consistent with (Kang et al., 2004; Kashyap & Panda, 2003).

Tubers weight: The effect of water treatments and interaction between (water levels and growth stages) on the weight of tubers was insignificant except at growth stages of SII and SIII.

Figure (5) showed that the deficit irrigation treatment WII has a clear effect on tuber weight during both SI and SIV stages (1573 and 1432 g, respectively). The least average tubers weight of the deficit irrigation treatment under the irrigation level of WIII was 1105 g in SII of the growth and 1163 g in the SIII stage. The shortage in irrigation water during the tubers' formation and cell development stages tends to reduce tubers' growth. (Chang, 1968) also indicated that the moisture-sensitive stages of potatoes were from stolonization to the beginning of tuberization. So, any deficit in irrigation, if accompanied with high temperature, will break the dormancy of the recently formed tubers which will start to grow up in soil, and if the soil moisture increases, tubers will give a secondary small growth causing the low weight of tubers. These results agreed with (Bailey & Groves, 1992; Fabeiro et al., 2001; Sadiq, 2013).

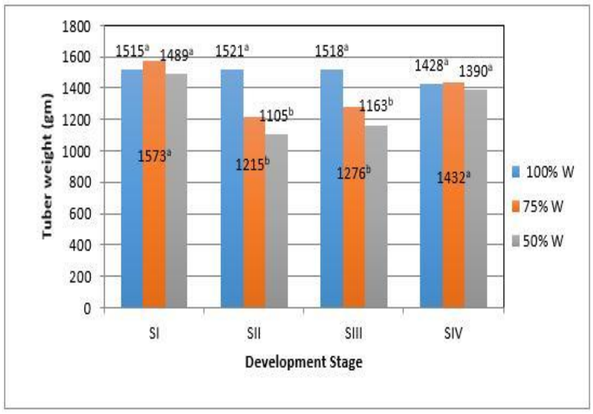

Figure (5). Effect of deficit irrigation treatment on average tubers weight per plant at various growth stages. LSD (P<0.05).

Tubers yield: The potato yield of the deficit irrigation treatments is shown in Figure (6). There was no significant difference between deficit irrigation treatments except for the SII growth stage, which had a significant difference. The interaction between deficit irrigation and growth stages was seen in SII. SIII has less effect than SII in all treatments of deficit irrigation. While the effect of treatments of deficit irrigation at the same stage was insignificant, the treatment 75% (WII) at SI gave more yield than treatment 100% (WI), while WI produced fewer yields. The lowest yield was found in treatment WIII with SII, and the highest yield was in treatment WII with SI. Other researchers as (Fabeiro et al., 2001), reported that 597 mm irrigation water was required to obtain a tuber yield of 45.18 t ha^{-1}. In another study, it was resulting that deficit irrigation should be avoided during tubers formation and at the middle of the maturity stage of potatoes to reach acceptable quality and quantity productivity (Kiziloglu et al., 2006). Water deficit has decreased the evapotranspiration and tuber yield of potatoes according to (Kiziloglu et al., 2006). These results of deficit irrigation showed that deficit irrigation had significant impact on yield. The amount of irrigation water was reduced as yield significantly decreased.

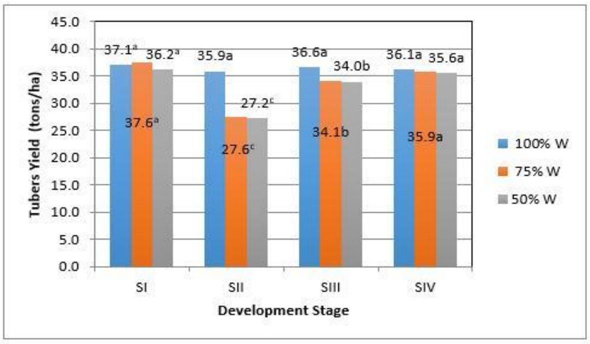

Figure (6). Tubers yield as affected by deficit irrigation treatment at different growth stages LSD (P<0.05).

Crop Water Consumption: Table (5) presents the results of water productivity (WP) and water use efficiency (WUE) for the different irrigation levels. The results showed that the best treatment in WP was recorded at deficit irrigation of WIII in SIII producing 6.231 kg/m^3, while the lowest yield value of 4.238 kg/m^3 was related to SII under deficit irrigation of WII, whereas the treatment WI at stages, SI, SII, SIII, and SIV gave 5.353, 5.187, 5.291 and 5.220 kg/m^3 respectively. Although the yield was 37589 kg ha-1 in the treatment of the irrigation deficit of WII at stage SI, its water productivity was 5.6 kg/m^3. (Rashidi & Gholami, 2008) illustrated that WP of potato in Iran ranged from 1.92 to 5.25 kg m^{-3}.Deficit irrigation had an effect on the yield and yield components at different levels of irrigation. Deficit irrigation had significant impact on yield and yield components at SII, which were obtained from levels WIII and WII which have the lowest. These results agreed with the research conducted by (Onder et al., 2005). Many irrigation studies indicated that a reduction in yield is a cause of deficit irrigation at different growth stages of the potato (Hassan et al., 2002).

The results of this study generally agree with the observation that an increase in water level 100% irrigation level leads to decreased WP (Erdem et al., 2006; Norwood, 2000; Shani & Dudley, 2001). The results of water use efficiency (kg/m^3) calculated from equation (4), showed that the maximum water use efficiency was 6.05 kg/m^3 at stage III and under irrigation treatment of WIII. On the other hand, the lowest value of WUE 4.15 (kg/m^3) was noted at stage II under irrigation treatment of WIII. WUE follow the same trend as WP. Stage II had the best values as compared with other stages. Like WP, the best values of WUE were also noted in WIII. The comparison between the values of the water productivity of crops and the efficiency of water use, both in units (kg/m^3), shows the loss of small quantities of water that the crop does not benefit from, which indicates the high efficiency of the irrigation systems used and the adoption of guided agricultural practices.However, by examining table (5), obtaining the largest possible crop yield regardless of the amounts of water added can be archived by adopting the WIISI treatment. Such intervention can be applied in cases of water abundance. On the other hand, regarding water scarcity, it is advised to apply the WIII SIII treatment to obtain the highest crop water productivity.

Table (5). Water productivity and water use efficiency for different stages and irrigation treatments.

Stages	Irrigation (level irrigation)	Crop Yield (kg/ ha)	Applied irrigation amount (m^3/ha)	$\frac{ET}{mm}$	$\frac{WP}{kg/m3}$	$\frac{WUE}{kg/m3}$
SI	WI	37061	6923	702	5.35	5.28
	WII	37589	6703	677	5.6	5.55
	WIII	36150	6484	662	5.57	5.46
SII	WI	35910	6923	701	5.18	5.12
	WII	27576	6507	665	4.23	4.15
	WIII	27227	6087	624	4.47	4.36
SIII	WI	36632	6923	691	5.29	5.3
	WII	34055	6191	635	5.5	5.36
	WIII	33966	5451	561	6.23	6.05
SVI	WI	36141	6923	702	5.22	5.15
	WII	35890	6646	681	5.4	5.27
	WIII	35586	6366	654	5.59	5.44

CONCLUSION

The results of this study found that the two stages SII (tuber initiation) and SIII (tuber bulking) in potato crop were the highest sensitivity to deficit irrigation compared to other stages. Thus, to obtain the best yield and yield components (number of tubers per plant, tuber weight, and plant weight of potato), Irrigation should be scheduled carefully during tuber formation. Based on the results obtained it can be recommended to avoid any reduction in the amount of irrigation water at the stage of tubers formation in order to obtain the highest tuber yield and better economic gains. Many similar studies must be conducted in different regions of Jordan since the soil and climate are different from one site to another.

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