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INFLUENCE OF MOISTURE DEPLETION AND SURFACE DRIP IRRIGATION STYLE ON SOME SOIL HYDRAULIC PROPERTIES AND POTATO CROP

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ABSTRACT. This study aimed to determinate the impact of soil moisture depletion and surface drip irrigation style on some soil hydraulic properties such as infiltration, hydraulic conductivity, application efficiency, and water use efficiency for the potato crop. A field experiment was carried out in a site located northeast Ramadi, Iraq. The study consists of two factors: the first factor was two levels of moisture depletion percentages 25 and 50%, while the second factor includes two surface drip irrigation styles, which were traditional surface drip irrigation and partial drying surface drip irrigation. Consumptive use for potato plant reached 32.05 cm during the growing season. Results showed a significant influence on the treatments on application and water use efficiencies as well as on infiltration and soil hydraulic conductivity. The combination of the treatments partial drying drip irrigation style and 25% moisture depletion percentage can be recommended to achieve the best irrigation management for potato plant, which improves soil hydraulic properties and meets the best plant response in the same time.

Introduction

Water resources are the most important natural resource related to the biological and human durability through the all activities including agricultural, industrial and urban usages. It is clear that water resources renewable through the hydrological cycle but the freshwater resources faced a shortage as compared with the areas of land, which are capable for agricultural investing. Water resources shortage is the most affected limits for irrigated agriculture in Iraq due to the geographical location, which located within arid and semi-arid regions. It resulted by the limited and irregular amount of precipitation. These conditions led to increase desertification and include more planted areas under desert bands as well as the impact of drought on rivers and subsurface water reservoir. It has been estimated that the Tigris and Euphrates river discharges will continue to decrease with time, and they will be completely dry by 2040 (Al-Ansari, 2013). Water resources shortages led farmers to think about new irrigation technologies including drip irrigation to increase water unit productivity (Tolk *et al*., 2016). To reach the best water unit productivity we have to schedule irrigation to meet fit crop needs, that will save water and increase irrigated area. Using of drip irrigation for vegetable crops exceeded when compared with the other irrigation methods especially in application efficiency, power saving, controlling weeds growth and water losses. In addition to that, drip irrigation may provide advantages for growers to enhance water use efficiency by achieving better control of soil water and nutrient utilization in the root zone (Reyes-Cabrera *et al*., 2014). Irrigated agriculture still the most used for the freshwater resources which reached about 70–80% from the total freshwater demand, both shortage and surplus of irrigation water produce problems in irrigated lands such as erosion and salinity (Shirish *et al*., 2013). Evapotranspiration affected by soil moisture percentage in the root zone also the water uptake by plants affected by the available soil moisture. When soil moisture tension increased the averages of evapotranspiration decreased (Shaw, 1964). Potato productivity studies showed that water is the most important factor, which affected yield (Panigrahi *et al.,* 2001).

Shock and Feibert (2002) mentioned that potato is one of the most sensitive plants for water stress. Many efficient irrigation methods applied for potato including drip irrigation, which reached 80% in application efficiency when compared with lower efficient surface irrigation methods in middle and south Iraq conditions (Abdul-Razak *et al.,* 2014).

Best irrigation management practices include controlling the applied water amount in each irrigation cycle. Application should be according to soil water holding capacity and plant requirements at each growth stage to meet the best plant production with fewer water losses. Drip irrigation is one of these practices due to the flexibility in applying the net depth of irrigation water amount. Irrigation can be applied within two or three batches with same time intervals between each other. Evans and Sadler (2008) mentioned that achieve high-frequency irrigation regimes is one of the factors can be used for water-saving by reducing losses through regulated deficit irrigation practices.

Reyes-Cabrera *et al.* (2014) presented drip irrigation for potato in Florida sandy soils as an alternative irrigation method with greater potential for water conservation than the traditional seepage irrigation; they also mentioned that the use of drip irrigation produces similar marketable yields of potato.

Potato plants showed a significant response to high-frequency irrigation methods. The results obtained by Kumar *et al*. (2009) cleared that drip irrigated potato registered 28.46% higher yield (mean of 2 years) over furrow irrigation. Their results also showed that the drip irrigation method also increased water use efficiency and fertilizer use efficiency when compared with furrow irrigation. Erdem *et al.* (2006) studied the effect of irrigation method (furrow and drip) and irrigation regimens (30, 50 and 70% soil moisture depletion percentages) on potato plant, their results cleared that increasing of soil moisture depletion percentages significantly decrease the potato yield for the growing season 2005. Roderick and Farquhar, (2002) found that potato tubers yield decreased when plants were underwater stress which was reached 33.63 megagram ha^{-1} as compared with 40.33 megagram ha^{-1} for the fully irrigated plants. Irrigation management practices, which save or improve soil physical properties led to improve the field condition for plant growth and production, Tartlan and Nugis, (2018) cleared that the improvement of soil bulk density produce a healthy condition for potato plants.

Potato consumptive use varying from site to other especially for high yield classes, water requirement for the best yield ranged between 400–800 mm season^{-1} according to climate conditions for the classes ranged in life cycle between 120–150 days (FAO, 2002). The results which obtained by Eid *et al*. (2013) showed that potato consumptive use ranged between 350–436 mm season^{-1} for different soil moisture depletion percentages, their results also cleared the increasing of soil moisture depletion percentages caused increase in the values of water use efficiency. A study conducted by Al-Kateeb *et al*. (2016) showed that potato consumptive use changed according to plant growth stages and it reached the highest value in tubers swelling stage while the lowest value was in vegetation growth stage. Kandil *et al*. (2011) presented that potato are one of the crops that planted in huge areas and it is the fourth economically important plant. Potato have a very high nutrition value due to the high content of carbohydrates, vitamins, minerals and some nutrients and it is one of the economic return plant (Bowen, 2003). In this study, we try to present and test partial drying surface drip irrigation as a management technology can be used to improve soil moisture condition in the root zone of potato plants as well as to evaluate the impact of this technology in some soil properties, irrigation efficiencies and plant response.

Materials and Methods

A field experiment was conducted during the fall season in silty loam soil at farm located about 4 km northeast Ramadi city, west of Iraq (latitude 33°27′49″ N, longitude 43°21′25.5″ E, altitude 48 m). A 0–30 cm depth, soil material sample was collected from the field and air-dried then sieved through 2 mm sieve for physical and chemical characteristics. Bulk density was 1.25 Mg m^{-3}, particle density was 2.63 Mg m^{-3}, porosity was 52.47%, volumetric water content at 0.3 bar was 33.04%, volumetric water content at 15 bar was 10.22%, available water was 22.82%. Hydraulic conductivity was 7.35 cm hr^{-1}, $pH_{1:1}$ was 7.21, Ca^{+2} 6.76 meq L^{-1}, Mg^{+2} was 4.55 meq L^{-1}, K^{+} was 0.11 meq L^{-1}, Na^{+} was 2.58 meq L^{-1}, CL^{-} was 0.12 meq L^{-1}, SO_4^{-2} was 12.28 meq L^{-1}, CO_3^{-2} was almost non-existent, HCO_3^{-} was 1.6 meq L^{-1}, and $EC_{1:1}$ was 1.4 dS m^{-1} determined according to Klute *et al.* (1986), Page *et al*. (1982) and Black (1965).

The field ploughed crossly and left some days for aeration then ground, levelled and divided to three blocks each one includes four experimental unites with 1.5 m distance between unites and 2.5 m between blocks. A factorial experiment using RCBD experimental design was carried out according to (Little and Hills, 1978). For the drip irrigation system Turbo type emitters were used with 4 L hr^{-1} flow rate at 0.5 bar operating pressure. Emission uniformity was tested before starting the experiment to be sure the system is working under optimum operating conditions. Potato tubers *Solanum tuberosum* L. class Riviera was planted with 0.08–0.10 m depth in 15/9/2017, distance between plants was 0.50 m. It was planted in one side of the lateral line for the traditional surface drip irrigation treatments and in the middle between two lines, which was 0.30 m for partial drying surface drip irrigation treatments. Fertilizers applied according to (Al-Kateeb *et al*., 2016). Anti-fungi treatments conducted using (Metalaxyl 8% WP + Mancozeb 64%) and for antiinsects (Alpha-cypermethrin) was used. Irrigation applied using water pumped from Euphrates river. The experiment includes two factors: soil moisture depletion percentage (D) and drip irrigation style (I) as cleared in Table 1.

Table 1. Treatments description

Treatments	Description
$I_PD_{0.25}$	Partial soil surface drying with 25% moisture depletion
$I_PD_{0.50}$	Partial soil surface drying with 50% moisture depletion
$I_FD_{0.25}$	Traditional drip irrigation with 25% moisture depletion
$I_FD_{0.50}$	Traditional drip irrigation with 25% moisture depletion

Application efficiency: calculated according to the following formula mentioned by (Heermann *et al.*, 1990).

$$Ea = \frac{Ws}{Wf} \times 100 \quad (1)$$

Ea – application efficiency (%).
Ws – volume of water stored in the root zone (m^3).
Wf – volume of delivered water (m^3).

Consumptive use: irrigation applied according to soil moisture depletion, which was 25 and 50%. Applied water depth changed due to plant growth stages and was calculated using the following formula (Kovda *et al.*, 1973):

$$d = \{\theta_{F.C} - \theta_{bi}\}\, D \quad (2)$$

d – applied water depth (cm).
$\theta_{F.C}$ – volumetric soil water content at field capacity ($cm^3\ cm^{-3}$).
θ_{bi} – volumetric soil water content before irrigation ($cm^3\ cm^{-3}$).
D – root zone depth (cm).

Table 2 shows plant growth stages according to Scherer *et al.* (1999). Plant coefficient were 0.75, 1.15, 1.00 and 0.80 for the stages of vegetation growth, tubers starting stage, tubers swelling and maturity stage respectively (Shiri-e-Janagrad *et al.*, 2009). Gravitational method was used for the stage before emerge because of no suggested factor found in the previous sources.

Table 2. Growth stages, root depth and stage duration for potato plant (Scherer *et al*., 1999)

Growth stage	Root depth	Stage duration
Before emerge	10	15/9–13/10
Vegetation growth	20	14/10–31/10
Tubers starting	25	1/11–19/11
Tubers swelling	30	20/11–16/12
Maturity	35	17/12–23/12

Irrigation scheduling through growth season calculated according to measuring evaporated water from American evaporation pan class A. When applied, water depth was equalled to actual evapotranspiration as the following formula:

$$ETa = d \quad (3)$$

Application efficiency assumed 0.89.

$$ETo = \frac{ETa}{Kc} \quad (4)$$

$$Ep = \frac{ETo}{Kp} \quad (5)$$

ETo – reference evapotranspiration (mm day^{-1}).
Ep – pan evaporation (mm day^{-1}).
Eta – potato plant consumptive use (mm day^{-1}).
Kp – pan coefficient which was (0.75) according to (Darra and Raghuvanshi, 1999).
Kc – potato plant coefficient. Values assumed according to Shiri-e-Janagrad *et al.* (2009) for the four growth stages.

Irrigation water applied as the Ep reached the calculated amount. Application time calculated according to the following formula (Martin, 2011):

$$q \times t = a \times d \quad (6)$$

q – flow ($m^3\ hr^{-1}$).
t – run time (hr).
a – irrigated area (m^2).
d – applied water depth (m).

Saturated soil hydraulic conductivity estimated according to (Black, 1965) while infiltration measured using double-ring infiltrometer according to (Haise *et al.*, 1956).

Water use efficiency: estimated according to the formula presented in (Allen *et al.*, 1998):

$$WUE = \frac{Y}{WA} \quad (7)$$

WUE – water use efficiency (kg m^3).
Y – yield (kg ha^{-1}).
WA – amount of applied water ($m^3\ ha^{-1}$).

Data analysis. Data were subjected to analysis of variance using Genstat (ver. 9.1, VSN International Ltd., Hemel Hempstead, UK). If interactions were significant, they were used to explain results. If interactions were not significant, means were separated with L.S.D.

Results and discussion

Results in the variance analysis table showed significant differences in all measured traits (Table 3).

Table 3. Analysis of variance for main effects of surface drip irrigation methods and allowed depletion percentage on application efficiency, saturated soil hydraulic conductivity, basic infiltration rate and water use efficiency

Source	df	Application efficiency	Saturated soil hydraulic conductivity	Basic infiltration rate	Water use efficiency
Block	2	0.0758	0.9172	0.34750	2.6069
Irrigation (I)	1	12.9169**	5.0311**	4.68750**	19.6608**
Depletion (D)	1	5.4271**	1.7557*	1.68750**	7.3947**
I × D	1	0.2437ns	0.0271ns	0.00750ns	0.0867ns
Error	6	0.4839	0.2728	0.02750	0.7847
Corrected Total	11				

ns – not significant; *significant at 0.05 level; **significant at 0.001 level, ANOVA.

Application efficiency. Table 4 shows the impact of soil moisture depletion and drip irrigation style on application efficiency; the data cleared a significant impact for the partial drying surface irrigation on application efficiency, which reached 91.49% as compared with 89.42 for the traditional surface drip irrigation. The reason could be due to the separation of irrigation water into two parts, a part applied in one side of the plants and the other part applied to the other side in the middle time between two irrigation cycles. This technique may reduce deep percolation as well as evaporation losses. The results also showed increase application efficiency for the 25% soil moisture depletion treatments, which reached 91.12% when compared with 89.78% for the 50 depletion percentages. The using of short irrigation intervals (high-frequency irrigation management) reduced irrigation water losses which reflected in improve application efficiency (Evans, Sadler, 2008). High-frequency irrigation management decrease the amount of the applied water in each irrigation cycle. This technique increases the chance for the soil to hold most of the applied water in the root zone and minimize losses by deep percolation and runoff.

Table 4. Influence of soil moisture depletion percentages and drip irrigation styles on application efficiency (%)

Irrigation	Depletion		
	D0.25	D0.50	Average
I_P	92.02	90.96	91.49
I_F	90.23	88.60	89.42
Average	91.12	89.78	Gm=90.45
$L.S.D_{0.05}$	I=0.983	D=0.983	I.D=NS

Consumptive use. Table 5 shows the applied water depth for the treatments, which reached 32.05 cm for all treatments. Irrigation water depth for the stage before emerge was 17.32 cm due to the high level of temperature during this period as well as the long duration for the stage. The amount reached 4.41 cm for vegetation growth stage then increased in the other stages, this could be due to development of plant root and shoot also the increasing of plant leafs area (Zhao, Cheng, 2005). Consumptive use decreased in maturity stage and amounted 1.08 cm due to the reduction of plant water demand as growth completed and plants parts begin dry as well as decrease temperature at this period. The amount of potato consumptive use was close to the results obtained by Eid *et al*. (2013).

Saturated soil hydraulic conductivity. Table 6 presents the impact of treatments on hydraulic conductivity; results cleared a significant impact for drip irrigation styles, which reached 7.38, and 6.09 cm hr^{-1} for partially dried treatments and traditional drip-irrigated treatments in succession. The reason may be due to the dividing of net irrigation depth which decreases dry-moisture cycles impacts on soil structure including particles dispersion and sedimentation process. This technique also had a minimum effect on soil bulk density and the percentage of the big pore spaces, which control water movement. The hydraulic conductivity reached 7.12 and 6.35 cm hr^{-1} for 25 and 50% depletion percentages and this may be due to short intervals between irrigations and the same reasons above. The results agreed with (Al-Kateeb *et al*., 2016).

Table 6. Impact of drip irrigation styles and depletion percentages on hydraulic conductivity

Irrigation	Depletion		
	D0.25	D0.50	Averages
I_P	7.81	6.95	7.38
I_F	6.42	5.75	6.09
Average	7.12	6.35	GM=6.73
$L.S._{D0.05}$	I=0.738	D=0.738	I.D=NS

Table 5. Pan evaporation, applied water depth and number of irrigation cycles for potato plants

Treatments	Growth stage	Number of irrigation cycles	Depth of pan evaporated water (mm)	Depth of applied water (mm)	Notes
IPD0.25	Before emerge	37	191.0	172.3	First irrigation cycle was in the same amount for all treatments to recharge soil moisture to be at field capacity. Applied depth was 2.83 cm.
	Vegetation growth	5	78.0	44.1	
	Starting tubers	5	58.4	50.0	
	Tubers swelling	4	55.0	43.3	
	Maturity	1	18.0	10.8	
IPD0.50 IFD0.25	Before emerge	19	191.0	172.3	Treatments IPD0.50 IFD0.25 received same number of irrigation cycles regardless the differences in depletion percentages.
	Vegetation growth	2+ stage complete	78.0	44.1	
	Starting tubers	2+ stage complete	58.4	50.0	
	Tubers swelling	2	55.0	43.3	
	Maturity	1	18.0	10.8	
IFD0.50	Before emerge	10	191.0	172.3	Stage complete means when growth stage completed but irrigation not required at the same time so water applied in amount calculated to recharge soil moisture to be at field capacity
	Vegetation growth	1+ stage complete	78.0	44.1	
	Starting tubers	1+ stage complete	58.4	50.0	
	Tubers swelling	1	55.0	43.3	
	Maturity	1	18.0	10.8	

Basic infiltration rate. Table 7 shows the impact of partial drying of the soil surface and traditional drip irrigation at 25 and 50% soil available moisture depletion percentages on basic infiltration rates. As one of the soil hydraulic properties (Horton *et al*., 1994), the impact of the treatments on soil basic infiltration rates have the same trends with saturated hydraulic conductivity. The statistical analysis clarified a significant influence for the irrigation style on infiltration. Basic infiltration rate in soil reached 8.10 cm hr^{-1} for partially dried treatment as compared with 6.85 cm hr^{-1} for the traditional drip-irrigated treatment. The reason may be due to the impact of traditional drip irrigation, which increases soil bulk density and decrease the porosity especially the fine pore spaces and that decreased the cross-sectional area for flow in soil body. On the inverse, the partial drying for soil surface caused decreasing in soil bulk density and increase porosity as compared with their values before planting which caused improvement in soil structure. The values of basic infiltration rates were 7.85 and 7.10 cm hr^{-1} for depletion percentages 25 and 50% respectively and this may be due to the high frequency in irrigation with low amounts of applied water as well as to the reasons mentioned above.

Table 7. Impact of irrigation styles and depletion percentages on basic infiltration rates

Irrigation	Depletion		
	D0.25	D0.50	Averages
I_P	8.50	7.70	8.10
I_F	7.20	6.50	6.85
Averages	7.85	7.10	GM=7.48
$L.S.D_{0.05}$	I=0.2343	D=0.2343	I.D=NS

Table 8. Impact of irrigation styles and depletion percentages on water use efficiency kg m^{-3}

Treatment	Parameter		
	Total yield kg ha^{-1}	Applied water volume m^3 ha^{-1}	Water use efficiency kg m^{-3}
I_P	12733.00	840	15.17
I_F	10600.00		12.62
$D_{0.25}$	12333.00		14.68
$D_{0.50}$	11000.00		13.10
$I_PD_{0.25}$	13466.33		16.03
$I_FD_{0.25}$	11199.72		13.33
$I_PD_{0.50}$	11999.70		14.29
$I_FD_{0.50}$	9999.75		11.90
$L.S.D_{0.05}$	I= 1.251	D= 1.251	I.D=NS

Water use efficiency. Table 8 shows the impact of depletion percentages and irrigation style on water use efficiency. The results cleared a significant impact for irrigation style, which reached 15.16 kg m^{-3} for partial irrigation as compared with 12.62 kg m^{-3} for traditional drip irrigation. Dividing the applied water into two parts led to decrease losses and improve soil moisture conditions, which increases the yield also may be due to the response of potato plant to high-frequency irrigation methods (Kumar *et al*., 2009). The values also reached 14.68 and 13.10 kg m^{-3} for 25 and 50% depletion percentages due to decrease irrigation intervals, which improve soil moisture condition for plants and reflected on yield. The results have the same trends with what obtained by Erdem *et al.* (2006); their results also showed the highest water use efficiency value was obtained for the treatment irrigated with lower depletion percentage in the 2005 growing season.

Conclusion

In order to improve irrigation water management in arid regions by testing a new practice for drip irrigation to achieve best soil moisture condition, we conduct this study for compare the new suggested practice named partial drying with the traditional surface drip irrigation. The impact of soil moisture depletion percentages also evaluated and potato plant was the biological indicator for the study. We can conclude that partial drip irrigation style led to improve the studied parameters including application efficiency, infiltration and water use efficiency, when compared with traditional drip irrigation as well as the 25% depletion percent, had a positive influence in soil hydraulic parameters and plant response compared with 50% soil available moisture depletion percentage.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

SA 50%, AS 25%, MA 25% – study conception and design;
SA 100% – acquisition of data;
SA 25%, AS 25%, MA 25% and GH 25% – analysis and interpretation of data;
SA 50% and AS 50% – drafting of the manuscript;
MA 50% and GH 50% – critical revision and approve the final manuscript.

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