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ESTIMATION OF CONSUMPTIVE USE OF POTATO CROP PIANTED UNDER DRIP IRRIGATION SYSTEM BY USING SWRT TECHNOLOGY

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Abstract: **A field experiment was carried out in the field of the College of Agriculture / University of Wasit, located on longitude 45° 50° 33.5° East and latitude 32° 29° 49.8° North, in Spring season of the agricultural season 2019, in order to estimate the water consumption of potato crop using SWRT technology and under the drip irrigation system. The experiment was designed according to Randomized Complete Block Design (RCBD) with three replications and four treatments that include of the SWRT treatment (the use of plastic films under the plant root area in an engineering style), and the treatment of vegetal fertilizer (using Petmos), organic fertilizer (sheep manure), and the control treatment . Potato tubers (*Solanum tuberosum* L.) var. Burin was planted for spring season on 10/2/2019 at the soil depth of 5-10 cm.**

The highest reference water consumption for the potato crop during the season was calculated by Najeeb Kharufa, which was 663.03 mm. The highest actual water consumption for the potato crop during the season for the control treatment was 410.1 mm. The results showed increase in the values of the crop coefficient (Kc) in the stages of tubers formation and tubers filling stage as compared to the vegetative and ripening stages, ranged from 1.37-1.92 for the two stages of tubers formation and tubers filling. The SWRT treatment gave the highest water use efficiency during the season, was 3.46 kg m^{-3} .

Key words: Reference water consumption , Actual water consumption , Crop coefficient , Potato.

I. INTRODUCTION

Modern technologies have been developed that use natural hydrological processes to retain the largest amount of water in the soil for a longer period, thus reducing water deficits for plants in arid and semi-arid regions. Among these modern technological are subsurface water retention technology (SWRT), in which plastic membrane are placed below the root growth zone with specific engineering methods, that aimed to improving the physical and hydrologic properties, minimizing water losses and increasing the productivity of these soils. Through field studies and agriculture in green houses, it was observed to increase the capacity of soil to preserve water and improve the root environment through preserving water and nutrients, thus improving the water qualities of soil and its productivity by using modern technology. These environmental and hydrological effects of SWRT technology increase the quantity and quality of both vegetable and cereal crops with using low amount of water and fertilizer. Experiences at the University of Michigan showed that erecting polyethylene films at a depth of 0.2m increase the water capacity of the root zone by twice compared to not using it [1,2].

This technology was applied in Iraq at the first time within peer program by [1], where it was implemented in Iraq at the first time in irrigated soils with a hot and dry climate during the years 2013-2016. It was noticed through studies conducted in Iraq on vegetable crops and by applying this technology that there is an increase in the efficiency of water use and an increase in the productivity of crop when rationing irrigation water and reducing the amount of added irrigation water to approximately 50% as a result of reserving water within the root zone of the plant [4-6].
Potato are among the most important vegetable crops in the world, especially in the Americas and Europe, in terms of productivity and cultivated area, as well as considers daily food for more than 75-90% of the world population [7]. Potato was Knew in Iraq in the twentieth century and its cultivation became widespread in 1960 [8]. Water consumption is defined as the sum of water consumed by the plant to build its tissues or what remains inside it or what is transpiration from the leaves to the air and what is lost from the soil by evaporation. Most previous studies showed that the consumptive use of potato reached 700-750 mm/ season .Because of few studies of consumptive use of vegetable crops

in general and for potato crop in particular in Iraq, therefore this study aims to estimate the reference water consumption (*ETo*), actual water consumption (*ET*a) , crop factor of potato crop (Kc) , and the water use efficiency.

II. Materials and Methods

Afield experiment was carried out in the field of College of Agriculture/ Waist University at the spring agricultural season 2019. Random samples were taken from several separate sites from the field soil and from three layers (0-15,15-30,30-45)cm. Each sample was mixed together and obtained a representative compound sample. The soil samples were air dried, then pulverized and sieved through 2mm diameter sieve. These samples were used to estimate the physical and chemical properties of the soil before planting, as following, a particles size analysis was carried out to find the texture by using the hydrometer method according to [9]. The bulk density of soil and particle density were estimated by core sample method and pycnometer method respectively according to the methods mentioned by [10]. The total porosity calculated by the relationship between bulk density and particle density according to [10] by the following equation:

$$f = 1 - \rho b / \rho s * 100 \quad \ldots\ldots\ldots\ldots(1)$$

as that
f : porosity(%)
ρ b : Bulk density of soil (Mg m^{-3})
ρs : Particle density of soil (Mg m^{-3})

The soil saturated hydraulic conductivity was estimated using the constant water column method according to [11] by the follow equation:

$$K = \frac{V\ L}{At\ \Delta H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

as that:
K : Saturated hydraulic conductivity(cm hr^{-1})
V : The volume of accumulated water out let of soil column (cm^3)
L: The length of the soil column (cm)
A : Cross section area of soil column (cm^2)
t: Water collection time (hr)
ΔH: The change of hydraulic head between intel and outlet of water to soil column (cm)

The accumulative infiltration and infiltration rate estimated by using the double ring infiltrometer, according to [12] as shown in the table below:

Table (1) : The physical properties of the field soil before conducting the experiment.

Soil property	Unit	Soil depth(cm)		
		0-15	15-30	30-45
Sand	G kg^{-1}	492	522	491
Silt		496	471	496
Clay		12	7	16
Texture class	Sandy Loam			
Bulk density	Mg m^{-3}	1.2	1.24	1.27
Particle density		2.61	2.59	2.60
Porosity	%	54	52	51
Water conductivity	Cm/hr	0.65	0.6	0.58
Infiltration rate		0.7		

Soil moisture characteristic curve was estimated by taking the moisture content values at different tension values, where the soil has been saturated with water for 24 hours and different tension values (0-15 bar) have been used by tension plate and pressure membrane where the volumetric moisture content has been calculated at each level of tension according to method [13] the data showed at fig.1.

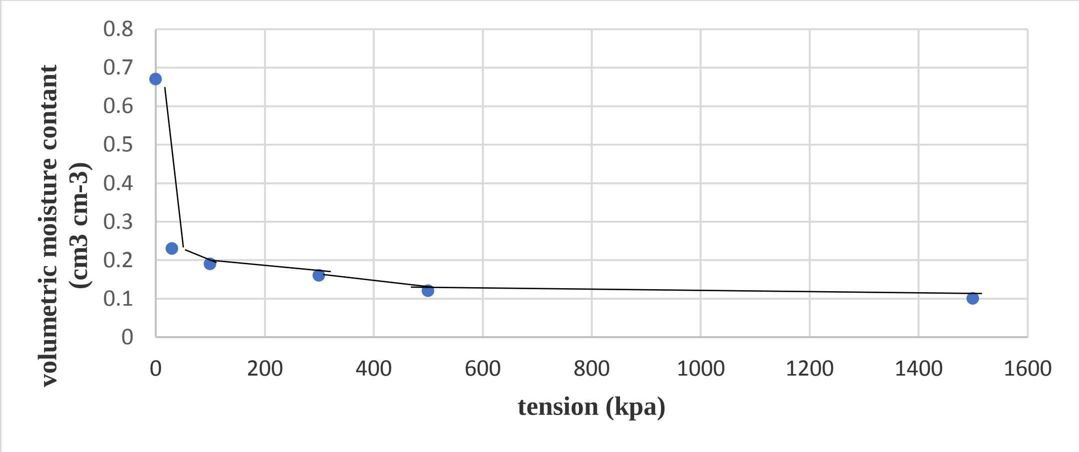


Fig.1 : Soil moisture characteristic curve for soil depth(0-30cm).

The experiment includes four experimental treatments and three replicates. By using randomized complete block design and the treatments are:

1. **SWRT treatment**

To apply this treatment required the use of transparent plastic films and was used to ditch trench with dimensions (0.5m ,0.5m ,10m) depth, width and length for each experimental unit, where these films were placed with a depth (0.5m) and a side slope of (1:1) and width (30cm) at the bottom, two trenches for each experimental unit were ditched. After that, the excavated soil was restored to its previous depth before digging as possible, as shown in fig.2 .

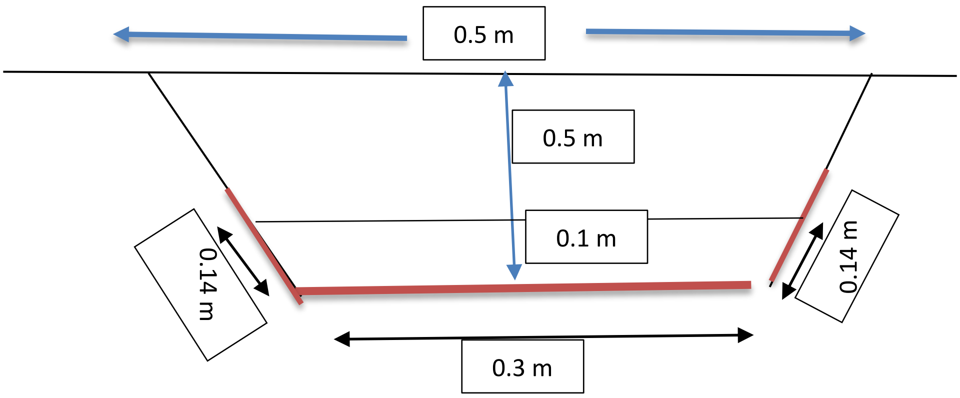


Fig.2 : A diagram showing the dimensions of the plastic film used in the experiment

2.Plant fertilizer treatment :

Plant fertilizer was used (ptmos) and two trenches were ditched with dimensions(0.5m ,0.5m,10m) depth, width and length for the experimental unit, and fertilizer was added at 44kg terrace^{-1},i.e.22 kg trench^{-1} according to the fertilizer recommendation 73-75 m^3 hectare^{-1}(10).

3. Animal manure treatment:

Animal manure was used as sheep waste(Al-Daman), and it was used to ditch two trenches were ditched with dimensions(0.5m ,0.5m,10m) depth, width and length for the experimental unit, and fertilizer was added at 44kg terrace^{-1},i.e.22 kg trench^{-1} according to the fertilizer recommendation 73-75 m^3 hectare^{-1} [14].

4. Comparison treatment:

(without using SWRT or adding plant and animal manure)

5. Preparing the field soil to planting:

The field soil is prepared by plowing the field soil with the moldboard plow, and it was smoothed by using the rodivatour and leveling by using the landplane, the dimensions of the field(10.75m*50m), the experiment field was divided into terraces, as the length of the terrace was 10m, width 2.25m and height 0.10m and the distance between the terrace and another 2.0 m , each block devided into four terraces with four treatments, and a distance of 2m was left longitudinally and transversely to prevent interaction between irrigation treatments. The number of experimental units reached twelve experimental units.

6. Installing the drip irrigation system:

Drip irrigation system has been installed in the field of experiment, which consists of the following parts: water tank with dimensions of 6*4*2m, gas pump 2 inch*2inch, fertilizer, filter, pressure gauge, control switches, main tube diameter of 2 inch, four semi-main pipes with a diameter of 2 inch, twenty four field tubes with a diameter of 16 mm, the distance between a side line and another 0.75m and the distance between emitter and another 25cm , each field tube contains 40 emitters. The system was examined and calibrated before planting, where emitters discharge and distribution uniformity were measured by the lowest quarter method by selecting four field-tubes, the first located at the beginning of the main line and the second and third located in the second and third quarters of the main line and the fourth is located in the last quarter of the line and four sites were selected in each field-tube is distributed over the four quarter, and the system was operate and put the glass beakers at the bottom of the chosen emitters, fix the time(2 minutes) for measurement, the discharge rate(liter/hour) and distribution uniformity (%) calculated as shown in table(2), remeasured after two days, and the discharge rate was approved for the used emitters is 5 L/hr.

Table(2) the mean emitters is discharge (L/hr) and distribution uniformity(%)

Field tube location on semi-main tube	Emitters location on field tube				
	beginning of field tube	second quarter of field tube	third quarter of field tube	End of field tube	The average
beginning of semi-main tube	5.18	5.34	5.46	5.04	5.26
Second of semi-main tube	5.15	5.09	5.26	5.1	5.15
third quarter of semi-main tube	5.29	5.39	5.25	5.03	5.24
End of semi-main tube	5.41	5.11	5.05	5.27	5.21
The average	5.26	5.23	5.25	5.11	5.21

Discharge rate(the lowest quarter) = 5.11 L/h
General discharge rate = 5.21 L/h
Distribution uniformity =5.11/5.21 * 100 =98.08%

7. Agriculture:

The potato tubers (Solanum tubersoum L.) Burin cultivar for a spring season were planted at (10/2/2019) at a depth of 5-10 cm and an average of 80 tuber for every terrace, a distance of 25 cm between one tuber and another [15].

8. Fertilization:

Urea fertilizer was used at a rate of 240 kg/ha in three batches at planting, stage of vegetative growth and the stage of tubers filling, and mono ammonium phosphate fertilizer (21% phosphorus and 11% nitrogen) at a rate of 120 kg/ha added at one batch at cultivation and potassium sulfate fertilizer (41.5% k) at a rate of 400 kg/ha added in two batches at planting and during the development tuber stage ,according to fertilizer recommendations by [16].

10. Control and Weeding:

The weeding process of weeds in the field took place over the period of the crop growth during the season, and the control process was not carried out because no pathological injuries occurred during the stages of crop growth.

11. Irrigation:

The irrigation process was carried out after the depletion of 50% of the available water, where the depth of the water needed to reach the soil moisture to the field capacity limits based on the data of soil moisture characteristic curve (as shown in table 3) where the content of the available water in the soil is estimated by the difference between the field capacity (content Volumetric moisture at a tension of 0.3 bar) and a permanent wilt point (volumetric moisture content at a tension of 15 bar) according to the following formula proposed from [17].

$$d =(\theta_{f.c} - \theta_{w})*D\text{……..(3)}$$

d: added water depth(cm) $\theta_{f.c}$: volumetric moisture content at field capacity (cm^3 cm^{-3}) θ_w: volumetric moisture content before subsequent irrigation (cm^3 cm^{-3}) D: depth of soil (cm) where a depth of 15 cm was used for the germination and vegetative stage , then icreased to 30cm in the stage of the emergence of tubers.

Based on the measurements of the irrigation water depth calculated in the above equation, the irrigation time is calculated for each area according to the equation given in [18,19].

T=d*Ae / Q ……….(4)

Ae: wetted area (m^2) d: depth of irrigation water (m) Q: emitter discharge (m^3/h) T: Irrigation time (hour).

Table (3) Moisture content and soil characteristics used in scheduling irrigation of experiment.

Property	Unit	Value
Volumetric moisture content □ at saturation	Cm^3 cm^{-3}	0.67
Volumetric moisture content □ at field capacity 0.3 bar		0.23
Volumetric moisture content □ at wilting point 15 bar		0.1
Available water		0.13
Volumetric moisture content □ at depletion 50% of available water		0.165
Gravimetric moisture content pw at field capacity	%	18.7
Gravimetric moisture content pw at depletion 50% of available water		13.41
Mean bulk density of soil to a depth of 0-30 cm	Mg m^{-3}	1.23

12. Yield:

The plants were extracted at120 days after planting, and the yield was estimated by the weight of tubers for each experimental unit separately and expressed as kg/plant and ton/hectare.

III. Equations used to estimate the reference water consumption ET_o for a potato crop

1- FAO Formula Penman- Monteith equation:

To estimate reference evapotranspiration used PM equation according to the equation given in [8] :

$$ET\circ = \frac{\left(0.408\times\Delta(Rn-G)+\gamma\left(\frac{900}{T+273}U_2(ea-ed)\right)\right)}{\Delta+\gamma(1+0.34U_2)} \quad \text{………….(5)}$$

ETo: Evapotranspiration reference of the crop(mm day^{-1}), R_n: Net radiation at the surface of the crop (mega joules m^{-2} day^{-1}) G: Soil heat flux (mega joules m^{-2} day^{-1}) , T: The average daily air temperature at 2m (c) , U_2: Wind speed measured at a height of 2m(m sec^{-1}) , ea: Saturated vapor pressure (kpa) , ed: Real vapor pressure (kpa) , ea-ed: Decrease in vapor pressure (kpa) , Δ :vapor pressure regression curve (kpa celsius) , γ : Psychrometric constant (kpa Celsius) , 900: Conversion factor.

2- Blany- Griddle Formula equation:

The Blany- Griddle equation was used to estimate the reference evapotranspiration. It is a simple experimental equation based on the average temperature and the percentage of daylight hours [20] :

$$ET_O = [Pn\times(0.46Tc+8.13)]\times Cp \quad \text{...........(6)}$$

ETo: reference evapotranspiration (mm day^{-1}) , T_c: Average monthly temperature (Celsius) , P_n: The percentage of the number of daylight hours per month to their number per year , c_p: Correction coefficient and equal according to the following equation :-

Cp=(0.0311 Tc + 0.24) …..…(7)

3- Najeeb- Kharrufa Formula equation:

The reference evapotranspiration is calculated according to the formula given in [21] :

$$ET_o = C.P.Tc^{1.3} \quad \text{……………..(8)}$$

C: A local coefficient for each site from the available climatic data rates for the months of June,July and August for a period of no less than ten years and calculated from the following equation given in(3),July, and the value of the constant (c=0.15) was adopted for the study site according to [22]:

$$C = 0.22 * \left[1 + \frac{n}{N}\right] * \left[0.9 + \frac{w}{100}\right] * (1 - 0.5\,RH) * \left[0.97 + \frac{E}{10000}\right] \quad ....(9)$$

$\frac{n}{N}$ **:** Sun brightness where n: represents the period of true sunshine , N: Maximum and possible sunshine period for the region , w: Wind speed (km/h) , E: Height of the site above sea level(m) , RH: Relative humidity(%)

4- Pan Evaporation Formula equation:

FAO has prepared an equation to calculate the reference evapotranspiration by evaporation from the evaporation pan(3) where the evaporation pan class A used by the office of Atmospheric weather in the United States is the most common, and the reference evapotranspiration is calculated according to the formula given in [17]:

$$ETo = Ep * Kp \quad ....(10)$$

ETo: reference evapotranspiration (mm) , kp: pan coefficient and extracted from the tables depending on the wind speed and relative humidity , Ep: The measured evaporation from the evaporation pan (mm)

5- Water Balance Formula (Inflow-Outflow):

Actual water consumption was calculated from the water balance formula presented in the following formula [17]:

$$(I + P + C) - (ETa + D_p + R) = \pm \Delta S \quad ....(11)$$

I: Added irrigation water depth (mm) , p: Rain depth (mm) , C: Height water with capillary (mm), *ETa*: Actual evapotranspiration (mm) , D_p : Depth of deep percolation (mm) , R: Run off (mm) , ΔS: The change in soil moisture storage between the beginning and end of the season(mm).

Assuming that:

R=0 because the earth is flat and there is no shallow runoff.

D=0 because the deep percolation loss is zero, C=0 because the water table is far from the soil surface.

ΔS=0 because the soil moisture content of the soil before planting and after the season was almost equal.

Yield factor:

The yield factor (kc) represents the ratio between actual water evapotranspiration and reference evapotranspiration and is calculated from the equation in (7) as follows:

$$Kc = ETa / ETo \quad ....(12)$$

Kc: yield factor, *ETa*: Actual evapotranspiration (mm) , *ETo*: reference evapotranspiration (mm).

Water use efficiency:

water use efficiency express the relationship of yield water in area unit to quantity of water used according to the equation given in [23] as follows:

$$WUEf = Yield / ETa \quad .... (13)$$

WUE_f: Field water use efficiency (kg m^{-3}) , Yield: yield crop (kg he^{-1}) , *ETa*: seasonal actual evapotranspiration at are unit as volume unit of irrigation water (m^3 he^{-1}).

Climate data: Climate data were obtained from Al-Kut meteorological station during crop growth stages for spring season, as shown in table (4).

Table (4) : Climatic data for the study area

month	Temperature(cilsius)			Relative humidity (%)	daylight hours	Wind speed(m/sec)	Evaporation (mm)	Rain (mm)
	min	max	average					
February 2019	9.26	19.22	14.24	69.64	6.9	2.92	2.8	24.8
March 2019	11.67	21.45	16.56	59.42	8.0	3.64	5.6	47.6
April 2019	14.34	23.12	18.73	48.85	8.7	3.64	6.3	26.5
May 2019	17.11	26.23	21.67	39.85	9.1	4.01	7.2	0.00

IV. Result and discussion

Reference evapotranspiration (*ET*o) for potato: Table (5,6) and Fig.3 show the values of the reference evapotranspiration for growth stages of potato crop for spring season2019 that calculated by equations of Najeeb Kharufa, Blany Criddle, evaporation pan and Penman Monteith respectively, the total reference evapotranspiration during crop growth season that calculated by Najeeb kharufa equation was the highest values and reached 663.03mm, followed by reference evapotranspiration calculated by Blany-Criddle equation was 522.61mm, then the reference evapotranspiration calculated by evaporation pan equation was 489.55mm , and the lowest values were the reference evapotranspiration calculated by Penman Monteith equation which was 399.37mm.

The reason for the rise in value of reference water evapotranspiration calculated by the Najeeb kharufa equation compared to values of reference evapotranspiration calculated by other equations is due to rise in values of climatic elements included in this equation, namely (temperature, number of hours of sun shine) with progress of growing season, in addition to rise in value of local coefficient(c) in this equation that calculated by [22] as mentioned previously.

The results also showed that the values of reference evapotranspiration increase with progress of crop growth stages for all equations,also the result calculated by Najeeb kharufa equation ranged from 93.16mm for germination stage to 176.36mm for maturity stage, and for Blany-Criddle equation ranged from 76.18mm for germination stage to 137.45mm for maturity, and for evaporation pan ranged from 42 mm for germination stage to 132.45mm for maturity, and for Penman Monteith equation ranged from 53.2mm for germination stage to 91.22mm for maturity, this is due to rise in values of climatic elements in the study area that included in these equations with progress of crop growth stages(temperature, solar radiation ,sun shine, evaporation, wind speed), for example temperature increased from 14.24c at February to 21.68c at May2019 and number of sun shine hours increased from 6.9 hours at February to 9.1 hours at May (table 4) this is result agreed with [24] that the reference evapotranspiration increases during dry months compared to wet months.

Table (5) :Reference evapotranspiration (*ET*o) calculated by experimental equations.

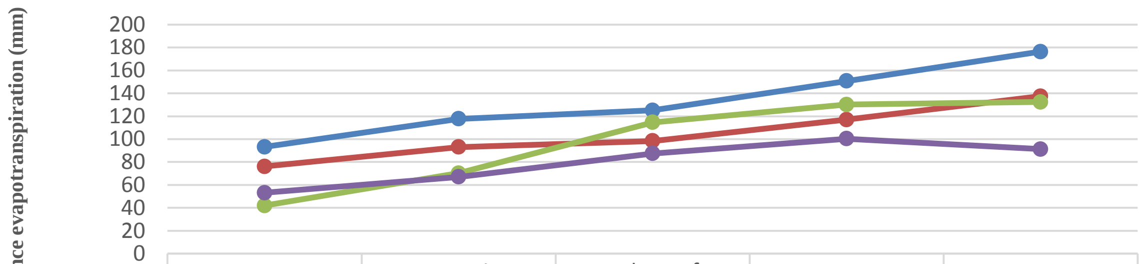
Growth stage	*ETo* calculated by Najeeb kharufa equation(mm)	*ETo* calculated by Blany Criddlel equation(mm)	*ETo* calculated by Evaporation pan equation (mm)	*ETo* calculated by Penman Monteith equation(mm)
Germination stage 10/2-1/3/2019	93.16	76.18	42	53.2
vegetative growth stage 2/3-21/3	117.66	93.08	70.22	67.03
Tubers emergence stage 22/3-16/4	125.18	98.42	114.66	87.51
Tubers filling stage 17/4-16/5	150.67	117.03	130.22	100.41
Maturity stage 17/5-26/5	176.36	137.45	132.45	91.22
Total	663.03	522.16	489.55	399.37

Actual evapotranspiration (*ET*a) for potato *ETa*: Table (6,7) show the actual evapotranspiration values for the study treatments during the crop growth stages. It is noted from the above two tables that the actual evapotranspiration value for SWRT treatment was 337.18mm, for plant fertilizer(compost) treatment was 353.28mm, for animal fertilizer treatment was 372.02mm, and for comparison treatment was 410.1mm, from these results, it is noted that the value of *ETa* for SWRT treatment were lower than *ETa* values for plant fertilizer, animal manure and comparison treatments with low rates 4.56% ,11.04% ,17.78% respectively, because of the low number of irrigations in SWRT treatment, which was 21 irrigations during the spring season compared to the number of irrigations for other treatments , which was 23irrigations for plant fertilizer treatment and 24 irrigation for each of animal manure and comparison treatments, This is due to the presence of plastic barrier in the treatment of SWRT, which contributes to maintaining a moisture storage close to field capacity, increasing the horizontal wet front, increasing the horizontal spread of wetted area above the plastic barrier, and reducing the water losses downward with deep percolation, which lead up to an increase the growth and spread of root system due to water retention with in , root zone and increase its efficiency use by plant under SWRT system, and this is consistent with what it found by [5] and [25].

The results of table(7) show that the depth of added irrigation water(I) without rain(R) for SWRT treatment was 259.58mm, while for plant fertilizer, animal manure and a comparison treatment was 275.68,301.42,332.5mm respectively, that indicating the contribution of SWRT treatment to providing depth of added irrigation water at a rate of 6.2%,16.12%,28.1% compared with treatments of plant fertilizer, animal manure, and comparison respectively. This indicates contribution of SWRT technology to reduce depth of irrigation water used compared with other studied treatments, consequently this will reduce the amount of added irrigation water, which increase water use efficiency by crop , this results agreed with [3,5].

The result of tables (6 ,7) showed increase of *ETa* with progress of stages of crop growth season and reached the highest value in stages of tubers development and tubers filling.The values of *ET*a of crop that added as water depth depletion between sequence irrigation was the highest values at tubers filling stage, where it was 89.32mm for SWRT treatment , 92.19mm for plant fertilizer treatment , 97.74mm for animal manure treatment and 110.3mm for comparison treatment, and when taking into account the depth of falling rain on study area, we notice that the depth of falling rain was 60.9mm in stage of tubers emergence and 5.1mm in tubers filling stage, which lead to increase *ETa* of tubers emergence stage compared tubers filling stage, In these two stage ,the actual evapotranspiration of plant increase due to increase of leaf area intercepted the sun rays and that accompaining increase in biological and physiological processes of plant, especially the process of photosynthesis and cell construction, increase of flowering process and emergence and filling of tubers, this two stages accompanied with increasing of temperature, wind speed, evaporation and daylight hours, this led to increase *ETa* for these two stages compared to germination stage, which was 28.95,47.58mm for vegetative growth stage and 45.21mm for maturity stage for SWRT treatment, but the other treatments took the same direction and agreed with [26].

Fig.3: Reference evapotranspiration (*ET*o) during the crop growth season.



	Germination	Vegetative growth	Tubers of emergence	Tubers filling	Maturity
Najeeb kharufa	93.16	117.66	125.18	150.67	176.36
Blany-Criddle	76.18	93.08	98.42	117.03	137.45
Evaporation pan	42	70.22	114.66	130.22	132.45
Penman Monteth	53.2	67.03	87.51	100.41	91.22

Najeeb kharufa Blany-Criddle Evaporation pan Penman Monteth

Growth stage

Table (6): Reference evapotranspiration (*ET*o) calculated by experimental equations actual evapotranspiration (*ET*a) and yield factor (kc) during the potato growth stages

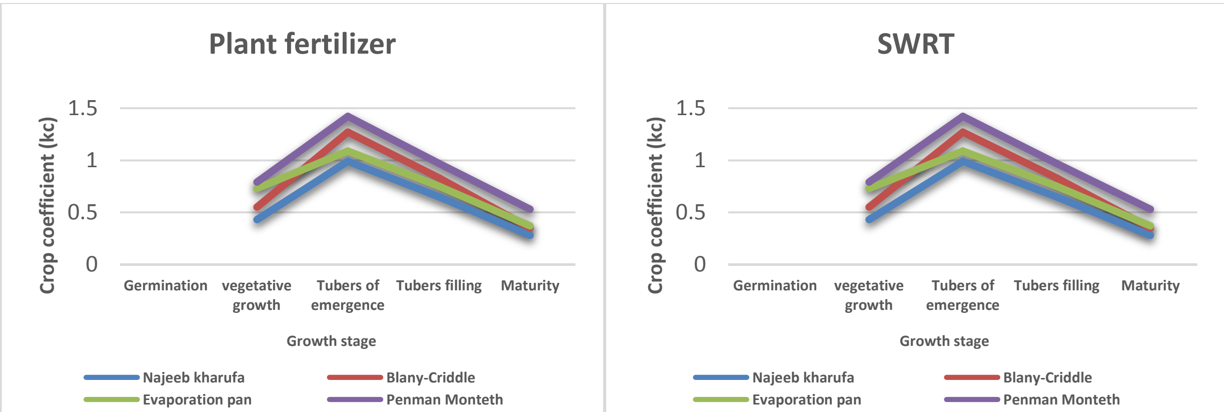
Treatments	Equations used to calculate	Germination stage 10/2-1/3				Tubers of emergence stage 22/3-16/4					Vegetative growth stage 2/3-21/3					Tubers filling stage 17/4-16/5					Maturity stage 17/5-26/5				
		*ET*o mm	I mm	R mm	*ET*a mm	*ET*o mm	I mm	R mm	*ET*a mm	kc	*ET*o mm	I mm	R mm	*ET*a mm	KC	*ET*o mm	I mm	R mm	*ET*a mm	kc mm	*E*To mm	I mm	R mm	*ET*a mm	kc
SWRT	Najeeb kharufa	93.16	25.45	3.5	28.95	117.66	39.48	8.1	47.58	0.4	125.18	60.12	60.9	121.02	0.97	150.67	89.32	5.1	94.42	0.63	176.36	45.21	-	45.21	0.26
	Blany-Criddle	76.19	25.45	3.5	28.95	93.08	39.48	8.1	47.58	0.51	98.42	60.12	60.9	121.02	1.23	117.03	89.32	5.1	94.42	0.81	137.45	45.21	-	45.21	0.33
	Evaporti on pan	42	25.45	3.5	28.95	70.22	39.48	8.1	47.58	0.68	114.66	60.12	60.9	121.02	1.06	130.22	89.32	5.1	94.42	0.73	132.45	45.21	-	45.21	0.34
	Penman Monteth	53.2	25.45	3.5	28.95	67.03	39.48	8.1	47.58	0.71	87.51	60.12	60.9	121.02	1.38	100.41	89.32	5.1	94.42	0.94	91.22	45.21	-	45.21	0.5
Plant fertilizer	Najeeb kharufa	93.16	28.32	3.5	31.82	117.66	42.98	8.1	51.08	0.43	125.18	63.65	60.9	124.55	0.99	150.67	92.19	5.1	97.29	0.65	176.36	48.54	-	48.54	0.28
	Blany-Criddle	76.19	28.32	3.5	31.82	93.08	42.98	8.1	51.08	0.55	98.42	63.65	60.9	124.55	1.27	117.03	92.19	5.1	97.29	0.83	137.45	48.54	-	48.54	0.35
	Evaporti on pan	42	28.32	3.5	31.82	70.22	42.98	8.1	51.08	0.73	114.66	63.65	60.9	124.55	1.09	130.22	92.19	5.1	97.29	0.75	132.45	48.54	-	48.54	0.37
	Penman Monteth	53.2	28.32	3.5	31.82	67.03	42.98	8.1	51.08	0.76	87.51	63.65	60.9	124.55	1.42	100.41	92.19	5.1	97.29	0.97	91.22	48.54	-	48.54	0.53
Animal fertilizer	Najeeb kharufa	93.16	32.11	3.5	35.61	117.66	45.01	8.1	53.11	0.45	125.18	71.4	60.9	132.3	1.06	150.67	97.74	5.1	102.84	0.68	176.36	55.61	-	55.61	0.31
	Blany-Criddle	76.19	32.11	3.5	35.61	93.08	45.01	8.1	53.11	0.57	98.42	71.4	60.9	132.3	1.34	117.03	97.74	5.1	102.84	0.88	137.45	55.61	-	55.61	0.4
	Evaporti on pan	42	32.11	3.5	35.61	70.22	45.01	8.1	53.11	0.76	114.66	71.4	60.9	132.3	1.15	130.22	97.74	5.1	102.84	0.79	132.45	55.61	-	55.61	0.42
	Penman Monteth	53.2	32.11	3.5	35.61	67.03	45.01	8.1	53.11	0.79	87.51	71.4	60.9	132.3	1.51	100.41	97.74	5.1	102.84	1.02	91.22	55.61	-	55.61	0.6
Compari son	Najeeb kharufa	93.16	35.74	3.5	39.24	117.66	48.33	8.1	56.43	0.48	125.18	79.09	60.9	139.99	1.12	150.67	110.3	5.1	115.4	0.77	176.36	59.04	-	59.04	0.33
	Blany-Criddle	76.19	35.74	3.5	39.24	93.08	48.33	8.1	56.43	0.61	98.42	79.09	60.9	139.99	1.42	117.03	110.3	5.1	115.4	0.99	137.45	59.04	-	59.04	0.43
	Evaporti on pan	42	35.74	3.5	39.24	70.22	48.33	8.1	56.43	0.8	114.66	79.09	60.9	139.99	1.22	130.22	110.3	5.1	115.4	0.89	132.45	59.04	-	59.04	0.45
	Penman Monteth	53.2	35.74	3.5	39.24	67.03	48.33	8.1	56.43	0.84	87.51	79.09	60.9	139.99	1.6	100.41	110.3	5.1	115.4	1.15	91.22	59.04	-	59.04	0.65

Table (7) :The actual evapotranspiration (*ETa*) for potato growth stages.

Treatment	Germination stage (mm)	Vegetative growth (mm)	Tubers emergence (mm)	Tubers filling (mm)	Maturity (mm)	ETa total I+R (mm)	I (mm)
SWRT	28.95	47.58	121.02	94.42	45.21	337.18	259.58
Plant fertilizer	31.82	51.08	124.55	97.29	48.54	353.28	275.68
Animal manure	35.61	53.11	132.3	102.84	55.16	379.02	301.42
Comparison	39.24	56.43	139.99	115.4	59.04	410.1	332.5

Crop coefficient(Kc) of potato: Fig.4 and table (6) show values of crop coefficient calculated from equation (12), and the values of Kc were calculated after end of germination stage for all treatments, the results showed increasing Kc values for all treatments with progress of growing season and then decrease at maturity stage,for example the Kc of SWRT treatment at vegetative growth ranged from 0.4-0.71 and ranged from 0.97-1.38 for tubers emergence, and then decrease in tubers filling stage and its value ranged from 0.63-0.94, while in maturity stage its value ranged between 0.26-0.5, while the other treatments took the same direction, for example the Kc values for comparison treatment ranged between 0.48-0.84 for vegetative growth stage and 1.12-1.6 for tubers emergence stage and 0.77-1.15 for tubers filling stage and 0.33-0.65 for maturity stage.

The result showed that the Kc values for all treatment were the highest in emergence and filling of tubers compared to other stages and this is due to increasing actual evapotranspiration of crop during these two stages due to breadth its vegetative group represented by leaf area as well as breadth and spread of root group which leads to increase its water requirements in these two stages, therefore the *ETa* values increase, for example the *ETa* values for plant fertilizer treatment in emergence and filling tubers stages reached 124.55mm and 97.29mm respectively, compared to actual evapotranspiration for other crop growth stages for the same treatment, that reached the values of actual evapotranspiration for stages of germination, vegetative growth and maturity 31.82, 51.08, 48.54mm respectively, and this agree with [27]. At the end of growing season (maturity stage), Kc values for all treatments decreased due to decrease in the actual evapotranspiration at this stage as a result of decrease plant requirements for, as well as increase climatic elements (temperature, number of luminous hours, wind speed, evaporation, solar radiation) leading to increase reference evapotranspiration(*ET*o) this is confirmed by [28].



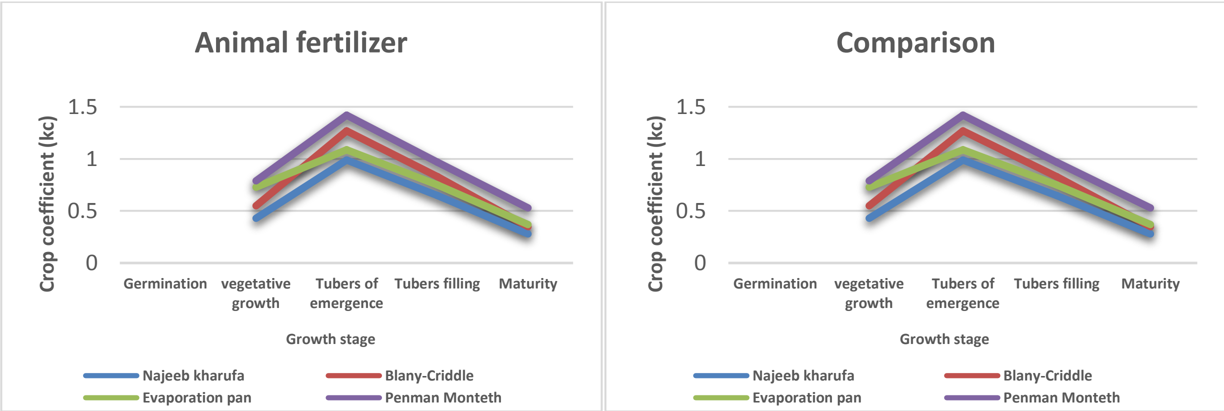


Fig.4: Crop coefficient (Kc) values during potato growth stages.

Water use efficiency: Fig.5 shows the effect of study treatments on water use efficiency during the growing season of potato crop, the season results showed superiority of SWRT treatment that it reached 3.46kg m^{-3} compared to plant fertilizer , animal manure and comparison treatments that gave efficiency of 2.96,2.66 and 2.34 kg m^{-3} respectively, the reason of superiority of SWRT treatment is attributed to the diaphragm membranes for this technique that maintains moisture content close to the field capacity in the root zone and the consumption of water is small and the quantities of added water are few and give a high yields, this shows that this technique increase the effectiveness of addition water through the number of irrigations perform in experiment, that decrease water consumption and increased production of potato**,** while comparison treatment was given the least efficiency due to decrease in total yield ratio to the large amount of water added to the field for this treatment [5].

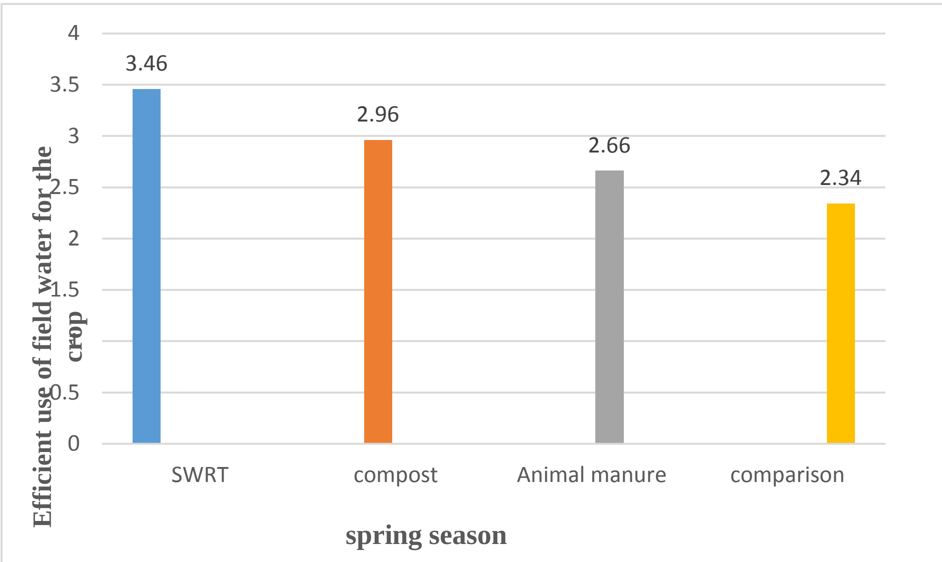


Fig.5: Efficient use of field water(kg m^{-3}) for the crop growing season

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