A Developed Criterion for Rationalizing On-Farm Irrigation Water Uses under Arid Conditions

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ABSTRACT:

Exploitation of irrigation water under arid ecosystem conditions becomes the pedagogical problem; therefore, rationalizing irrigation and with maximizing water use efficiency based on appropriate developed technologies are the most important aspects in the water and agricultural policies. Therefore, the objectives of this study were to: 1) develop out a criterion to identify irrigation system effectiveness by using a dimensionless analysis; and 2) validate the suggested criterion

Dimensional analysis outputs revealed that the irrigation efficiency, may be better if it replaced by new developed terminology noted as irrigation effectiveness for calculating the seasonal crop water requirements (SCWR) that represent a ratio of irrigation system performance and irrigated soils. The developed criterion may be expressed as follows:

$$E_{idc} = \frac{S_{pi}}{I_{pi}} = \frac{\left[\left[\frac{\sum (q_i - q_n)^2}{\bar{q} * n * p}\right] * \frac{t}{DU} * \frac{1}{w}\right]}{\left[\frac{M.C_{after} - M.C_{before}}{[F.C - P.W.P]}\right] * \left[\frac{d}{T_i} * \ln(k)\right] * [f * n] * coneversion}$$

Moreover, results analysis of the validation process of the developed criterion indicated that SCWR had been improved by applying the developed criterion with about 10.55 – 21.56 % comparing with that had been applied according to the conventional calculated method that had been recommended by FAO.

Keywords: Micro-irrigation, Soils, Dimensional analysis, Irrigation efficiency, Irrigation, Water use efficiency.

INTRODUCTION:

Dwindling water resources and growing competition for water will reduce water availability for agricultural development processing, while the need to meet growing food demands will require that more food is grown with less water. A more effective water and greater water productivity will be a primary challenge for future development **(El-Nemer, 2014 and Khalifa *et al.*, 2014)**. Due to excess or deficient levels of water or nutrients can result in yield reductions, proper design and management processes of micro-irrigation system are essential for successful production. Systems must integrate soil-hydro-physical properties, crop root distribution characteristics, water requirements related to crop growth stage and environmental demand (**Arafa *et al.;* 2013; ASABE, 2012; Kamal and Vencent, 2005; Clark *et al.*, 1999; and Burt and Styles, 1994)**

There is no doubt that the average crop yield is a function of the irrigation water application factors (application uniformity; depth of application and the amount of daily evapotranspiration supplied by rainfall), the hydraulic variation of distributors as well as the crop sensitivity to the moisture stress. Application uniformity depends on the manufacture's uniformity of the selected distributors, the hydraulic design and the systems maintenance program **(Mehawed *et al.*, 2013)**. Following early research into the amount of water required for crop production, water use efficiency becomes a widely used agronomic term to express the efficiency of production per unit of water required. The agronomic characterization is different from engineering definition in which WUE refers to the ratio of water delivered to water supplied implying the losses incurred in transporting the water to the crop **(Hagag and Mattar, 2005; Hanafy *et al.*, 2005; and Steduto and Smith, 2000)**. Supply of water through irrigation involves the caption of water from the source, the transport through the irrigation system (i_{ce}), the distribution on the farm (i_{ef}) and the application to the field and to the crop **(Enciso, *et al.*, *2005*)**. **Al-Jamal *et al.* (2001)** mentioned that water management will become an important practice used. Irrigation efficiency (IE) is an important factor into improving water management but so is economic return therefore we will have a comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. Irrigation engineers when designing an irrigation system try and maximize irrigation.

Patel and Rajput (2008) and hypothesized that improved yields from subsurface drip systems are most likely due to more water being available to the plants, as compared to surface drip because of less evaporation in subsurface drip system. **Burt *et al.* (1997)** and **Slavil and Zavadil (1999)** noted that crop evapotranspiration (ET) would be less for a well-watered crop with dry soil and plant surfaces (that is possible with subsurface drip system) than if the crops were to be irrigated with a method that wets the soil and plant surfaces. On the other hand, **El-Raie and Abdel-Wahab (2005)** and stated that the appropriate selection of the CWU method under diverse micro-climatic regions had to be considered for improving water uses under arid and semi-arid conditions. **Kumar *et al.* (2007) and Alazba (2002)** developed functions that can be used as a guide to yield potential allocation decision related to limited irrigation water. However, the transport of on-farm irrigation water to cope the crop-water requirements' is overcoming three levels of management that could be distinguished as: 1) the on-farm irrigation system managed by an irrigation agency; 2) the farm system managed by a group of farmers and/or an individual farmer and 3) the field system managed by the individual farmers.

Hereby, the objectives of this study were to: 1) develop out a criterion to identify irrigation system effectiveness by using a dimensionless analysis; and 2) validate the suggested criterion

METHODOLOGY:

Each level is subjected to losses and the technical sophistication of the hydraulic pathway and management of the irrigation system determines to a large extent the efficiency of the irrigation systems. However, the first and second levels play a crucial role in the effective management of on-farm irrigation water.

1- Dimensional and data analysis

Factors affecting the performance analyses of on-farm irrigation systems had been gathered, analyzed and evaluated, in order to observe the dimensionless group. Also, data that represents the soil characteristics for managing the irrigation water had been gathered and evaluated for the same purpose. After then, the observed dimensionless groups had been verified individually; then all groups had been validated under Field conditions for validation process.

i – Irrigation performance analyses index (I_{pi}):

Water stressed is a vital to use irrigation water efficiently. However, using irrigation systems that apply more uniformly and in limited amounts to avoid water stress in plants and to prevent excessive drainage is a crucial objective under arid ecosystems conditions. Herby, it can be concluded that the irrigation efficiency of localized irrigation systems is a function of distribution uniformity with which water discharged from the distributor devices.

From a point of view towards pressurize irrigation systems in general and localized irrigation in particularity, wherever, the forced stream through pipelines is the man factors of flow, we can accordingly clarified that both conveyance efficiency and farm efficiency can be negligible, however, their values are approximately to be a comply the maximum values, and their losses can be neglected too. After then, the most important efficiency that affected the performance of those irrigation system is that the application efficiency. Hereby, the factors that maybe affecting the optimizing of the localized irrigation systems efficiencies are analyzed below.

ii – Soils performance index (S_{pi}):

Application of predicting models for optimizing localized irrigation systems efficiency needs information about hydro-physical properties, especially hydraulic conductivity under saturated and unsaturated conditions. In addition, other parameters such as field capacity and permanent wilting point that indicate soil texture may need to confirm the logical relation between them.

a- Soil hydraulic resistance

The *resistance* to vertical flow (R_i) of the $i-th$ soil layer with a *saturated* thickness d_i and vertical hydraulic conductivity Kv_i is:

$R_i = d_i / Kv_i$

Expressing Kv_i in m/day and d_i in m, the resistance (R_i) is expressed in days. The total resistance (Rt) of the soil profile is:

$$Rt = \Sigma R_i = \Sigma d_i / Kv_i$$

where Σ signifies the summation over all layers: i= 1, 2, 3, . . .n
The *apparent* vertical hydraulic conductivity (Kv_A) of the soil profile is:

$Kv_A = Dt / Rt$

where Dt is the total thickness of the soil profile: Dt = Σ d_i, with i= 1, 2, 3, . . .n

The resistance plays a role in soil profile where a sequence of layers occurs with varying horizontal permeability so that horizontal flow is found mainly in the layers with high horizontal permeability while the layers with low horizontal permeability transmit the water mainly in a vertical sense. When the horizontal and vertical hydraulic conductivity (Kh_i and Kv_i) of the (*i-th*) soil layer differ considerably, the layer is said to be anisotropic with respect to hydraulic conductivity. When the *apparent* horizontal and vertical hydraulic conductivity (Kh_A and Kv_A) differ considerably, the soil profile is said to be anisotropic with respect to hydraulic conductivity. When calculating flow to drains though soil profile with the aim to control the water table, the anisotropy is to be taken into account; otherwise the result may be erroneous.

b- Transmissivity

The Transmissivity is a measure of how much water can be transmitted horizontally, such as to the tile drains. Soil profile may consist of n soil layers. The Transmissivity for horizontal flow T_i of the (i – th), soil layer with a *saturated* thickness d_i and horizontal hydraulic conductivity K_i is:

$$T_i = K_i d_i$$

Transmissivity is directly proportional to horizontal hydraulic conductivity K_i and thickness. d_i Expressing K_i in m/day and d_i in m, the Transmissivity T_i is found in units m^2/day. The total Transmissivity T_t of the soil profile is the signifies the summation over all layers i= 1,2,3,…,n. When the soil layer is entirely below the water table, its saturated thickness corresponds to the thickness of the soil layer itself. When the water table is inside a soil layer, the saturated thickness corresponds to the distance of the water table to the bottom of the layer. As the water table may behave dynamically, this thickness may change from place to place or from time to time, so that the Transmissivity may vary accordingly. However, the estimation of K from grain size could be gotten from Allen-Hazen derived an empirical formula for approximating hydraulic conductivity from grain size analyses:

$$K = C(D_{10})^2$$

Where: C is the Hazen's empirical coefficient, which takes a value between 0.4 and 10.0, with an average value of 1.0. $\rho b / \rho s \leq 1$ is packing system of soil particles which refers to soil porosity and therefore indicates the efficiency of soil tillage. Small this ratio indicates good aeration in soil and suitable tillage operation. While as this ratio increases this means soil tended to compacted or consolidated and characterized with bad aeration and high penetration resistance needs high power in plowing and through using other soil machines; **n** value in **van Genuchten model (1980)** affects the slope of the Soil Water Characteristics Curve for suctions greater than the air entry suction (y_a). The slope becomes increasing negative as **n** value decreases. The value for **n** is always > 1 generally fluctuated between 1.1 to 1.3 for well-structured clay soil and from 1.4 to 1.8 for medium and light textured soil. The great value of **n** refers to raped and easily water depletion from the soil, so it can be closely related to the period between irrigations. As the soil slope is increases finger flow (Flow of water into macro pores in vertical direction) is decreased while lateral flow tended to increase may resulting in decreasing the efficiency of soil water distribution. However, different hydro-physical characteristics of the Egyptian soils had been gathered and analyzed, as shown in **Table (1).**

- **Effect of "n " on hydraulic conductivity: n** value affects the slope of the hydraulic conductivity for suctions greater than the air entry suction (y_a). The slope becomes shallower as n decreases.
- **Effect of "α " on Soil Water Content Curve: α** value (alpha) affects the breakpoint in the curve, commonly referred to as the air entry suction (y_a). The air entry suction increases as **α** value (alpha) decreases.
- **Effect of "α " on hydraulic conductivity: α** value (alpha) affects the breakpoint in the curve, commonly referred to as the air entry suction (y_a). The break point occurs at higher suctions as **α** (alpha) value decreases

Table 1. Egyptian soil hydro-physical properties under arid conditions.

Texture Class	N	-- θr -- cm^3/cm^3		-- θs -- cm^3/cm^3		-- log(α) -- log(1/cm)		-- log(n) -- log10		-- Ks -- log(cm/day)		-- Ko -- log(cm/day)		-- L --	
Clay	84	0.098	(0.107)	0.459	(0.079)	-1.825	(0.68)	0.098	(0.07)	1.169	(0.92)	0.472	(0.26)	-1.561	(1.39)
Clay loam	140	0.079	(0.076)	0.442	(0.079)	-1.801	(0.69)	0.151	(0.12)	0.913	(1.09)	0.699	(0.23)	-0.763	(0.90)
Loam	242	0.061	(0.073)	0.399	(0.098)	-1.954	(0.73)	0.168	(0.13)	1.081	(0.92)	0.568	(0.21)	-0.371	(0.84)
Loamy Sand	201	0.049	(0.042)	0.390	(0.070)	-1.459	(0.47)	0.242	(0.16)	2.022	(0.64)	1.386	(0.24)	-0.874	(0.59)
Sand	308	0.053	(0.029)	0.375	(0.055)	-1.453	(0.25)	0.502	(0.18)	2.808	(0.59)	1.389	(0.24)	-0.930	(0.49)
Sandy Clay	11	0.117	(0.114)	0.385	(0.046)	-1.476	(0.57)	0.082	(0.06)	1.055	(0.89)	0.637	(0.34)	-3.665	(1.80)
S C L	87	0.063	(0.078)	0.384	(0.061)	-1.676	(0.71)	0.124	(0.12)	1.120	(0.85)	0.841	(0.24)	-1.280	(0.99)
S loam	476	0.039	(0.054)	0.387	(0.085)	-1.574	(0.56)	0.161	(0.11)	1.583	(0.66)	1.190	(0.21)	-0.861	(0.73)
Silt	6	0.050	(0.041)	0.489	(0.078)	-2.182	(0.30)	0.225	(0.13)	1.641	(0.27)	0.524	(0.32)	0.624	(1.57)
Si Clay	28	0.111	(0.119)	0.481	(0.080)	-1.790	(0.64)	0.121	(0.10)	0.983	(0.57)	0.501	(0.27)	-1.287	(1.23)
Si C L	172	0.090	(0.082)	0.482	(0.086)	-2.076	(0.59)	0.182	(0.13)	1.046	(0.76)	0.349	(0.26)	-0.156	(1.23)
Si Loam	330	0.065	(0.073)	0.439	(0.093)	-2.296	(0.57)	0.221	(0.14)	1.261	(0.74)	0.243	(0.26)	0.365	(1.42)

iii - Theoretical therapy:

The concepts of water use efficiency are introduced for the purpose of optimizing localized irrigation efficiency and the technical and agricultural options to increase production with less water elaborated. Efficiency is generally associated with a transformation process in which an input is transformed into an output. Therefore, the overall irrigation efficiency is defined as the fraction of water diverted to the irrigation system, which is ultimately effectively stored in the root zone and utilized effectively by plant in avoidance of plant-water stresses. The effective irrigation efficiency is characterized as a function of both irrigation systems equivalent parameters, soils equivalent parameters and application time.

2- Validation process:

Field experiments were carried out during two successive growing at a farm located at Longitude 30° 13' 0 E°, latitude 30° 25' 0 N and 25.5 m above MSL, that represents sandy soils conditions of the newly reclaimed soil of the Egypt. The analyses to determine physical and hydro-physical characteristics of the soil site had been conducted according to standard methods and presented in **Table (2).** Surface and subsurface drip irrigation systems networks were installed at the experimental site. A split-split plot design was used in this experiment. However, the area was divided into two main, every plot was divided into three sub-plots each (90×30m) for drip irrigation treatments (SD, SSD_{10} and SSD_{20}).

Table (2): Soil physical properties of the experimental site.

Soil layer, cm	Particle size distribution, %			Texture class	B. D (gm/cm^3)	Moisture content by weight (%)		
	Sand	Silt	Clay			F. C	P.W.P	A.W
0 –20	94.5	3.5	2.0	Sandy	1.65	8.03	3.33	4.7
20-40	95.0	3.3	1.7	Sandy	1.56	9.13	3.14	5.99
40-60	95.7	3.0	1.3	Sandy	1.44	10.07	2.99	7.08

F.C = Field capacity, P. W.P =Permanent Wilting point, A.W= Available water B.D= Bulk density

a- Cultivated crop:

Onion crop (*Allium Cepa L.*), Giza 20 for two successive growing seasons (2011-2012) and (2012 -2013), the cultivated area was prepared into leveled basins of (30×30m) for each treatment, and transplanted of onion seeds on Dec. 2011 in the first season and on Dec. 2012 in the second season, meanwhile, harvesting had been taken place on April of each growing season. The sawing was done in row at plant spacing of 14.3 cm between plants and the spacing between plant's rows was varied according to the number of cultivated plant's rows around laterals. All agronomic practices and the rate of applications were applied as recommended by Vegetable Research Institute, ARC, MALR, Egypt. The crop began to show signs of maturity (over 70% dropping of leave head) at 12 and 14 weeks after germination. Harvesting was carried cut about one week after, particularly 10th April 2012 and 13th April 2013. The area of 3 m in long and 1 m in wide in each plot were lifted (without discards), properly labeled and taken to be to laboratory to curve for about two weeks. Therefore, the onion bulbs were separated from the dry matter and weighed.

b- Calculation methods of the applied amounts of irrigation water:

Onion plant-water requirements were calculated and scheduled. However, Reference evapotranspiration of the studied area had been gathered from Central Laboratory of Agricultural Climate (CLAC), Agriculture Research Center (ARC) for the cultivated growing seasons. After then, these gathered data were analyzed and processed according to investigated level of treatments, as described later. Reference evapotranspiration (ETo) was computed using the FAO, modified Penman-Monteith method as given in **Allen *et al* (1998).** ETo data were processed by using CropWat 8.1 model, for all calculation based on FAO method, or were processed to be used for calculation by using the developed criteria method.

$$\mathbf{CWU = kc * ET_0;\ \ SCWR_{FAO} = CWU/E_a\ ;\ and\ SCWRE_{idc} = CWU/E_{idc}}$$

c- Treatments:

i- Actual Evapotranspiration treatments:

FAO: determination of actual evapotranspiration based on traditional method that had been described by **FAO**

E_{dic}: determination of actual evapotranspiration based on the developed criterion

ii- Irrigation systems treatments:

SD: surface drip irrigation system treatments.

SSD_{10}: subsurface drip irrigation system with buried laterals at 10 cm depth treatments.

SSD_{20}: subsurface drip irrigation system with buried laterals at 20 cm depth treatments.

d- Measurement and calculations:

1. Soil Water and Salts Distribution Pattern under Deficit Irrigation Treatments: Soil samples were taken periodically during each growing season in order to determine soil moisture distribution patterns under each treatment. Meanwhile, soil samples were taken twice (one before cultivation season and the second after harvesting) in order to determine salt distribution patterns under each treatments, the soil samples were taken around the emitter, at 10cm depth and 20 cm. Data were exposed to SURFER 7.

2. Computation of Crop-Water Use (CWU), Seasonal Crop Water Requirements (SCWR): The crop water use, seasonal crop water use and seasonal crop water requirements at each onion plants growing stage were calculated, determined based on the calculation method base.

RESULTS AND DISCUSSION:

1- Dimensional analysis outputs of the developed criterion:

a – Irrigation performance parameters index:

The observed irrigation performance parameters that affecting the optimizing localized irrigation systems efficiency can be formed as follows:

$$I_{ppi} = \left[\frac{\sum (q_i - q_n)^2}{\bar{q} * n * p} \right] * \frac{t * w}{DU}$$

Whereas:

q_i : is the actual discharge of the distributor devices, m^3/h.

q_n : is the nominal discharge of the distributor devices, m^3/h.

$\bar{q}$: is the mean discharge rate of the distributor devices,

m^3/h.

N : is a fraction of the clogging risks, fraction.
P : is a fraction of pressure variation sensitivity (pressure drop fraction).
DU : is the distribution uniformity, %.
T : is the operating time of irrigation event, h.
W : is the effective coverage width of the irrigated soils

b – Soils performance parameters index:

The observed index comply the following relationships between the soil hydro-physical parameters based on a mathematical and logic analyses. The developed formula maybe summarized as follows:

$$S_{ppi} = \left[\frac{M.C_{after} - M.C_{before}}{[F.C - P.W.P]} \right] * \left[\frac{d}{T_i} * \ln K \right] * [f * n] * coneversion$$

Whereas:

$M.C_{before}$: is the soil moisture content before irrigation in equivalent volumetric units, %.
$M.C_{after}$: is the soil moisture content after irrigation in equivalent volumetric units, %.
F.C : is the soil field capacity, %.
P.W.P : is the permanent wilting point, %.
K : is the soil hydraulic conductivity, cm/h.
T_i : is the soil Transmissivity, mm^2/day
D : is the applied irrigation water depth at each irrigation event, mm

F : is the soil porosity, fraction.
N : is an indices depend on the soil layer texture, which ranged from 1 – 1.6, fraction

c- Developed criterion "E_{idc}":

$$E_{idc} = \frac{S_{ppi}}{I_{ppi}}$$

Wherever:

E_{idc} : is the effective irrigation developed criterion.
S_{pp} : is the soil performance parameter.
I_{pp} : is the irrigation performance parameter.

2- Validation process outputs of the developed criterion:

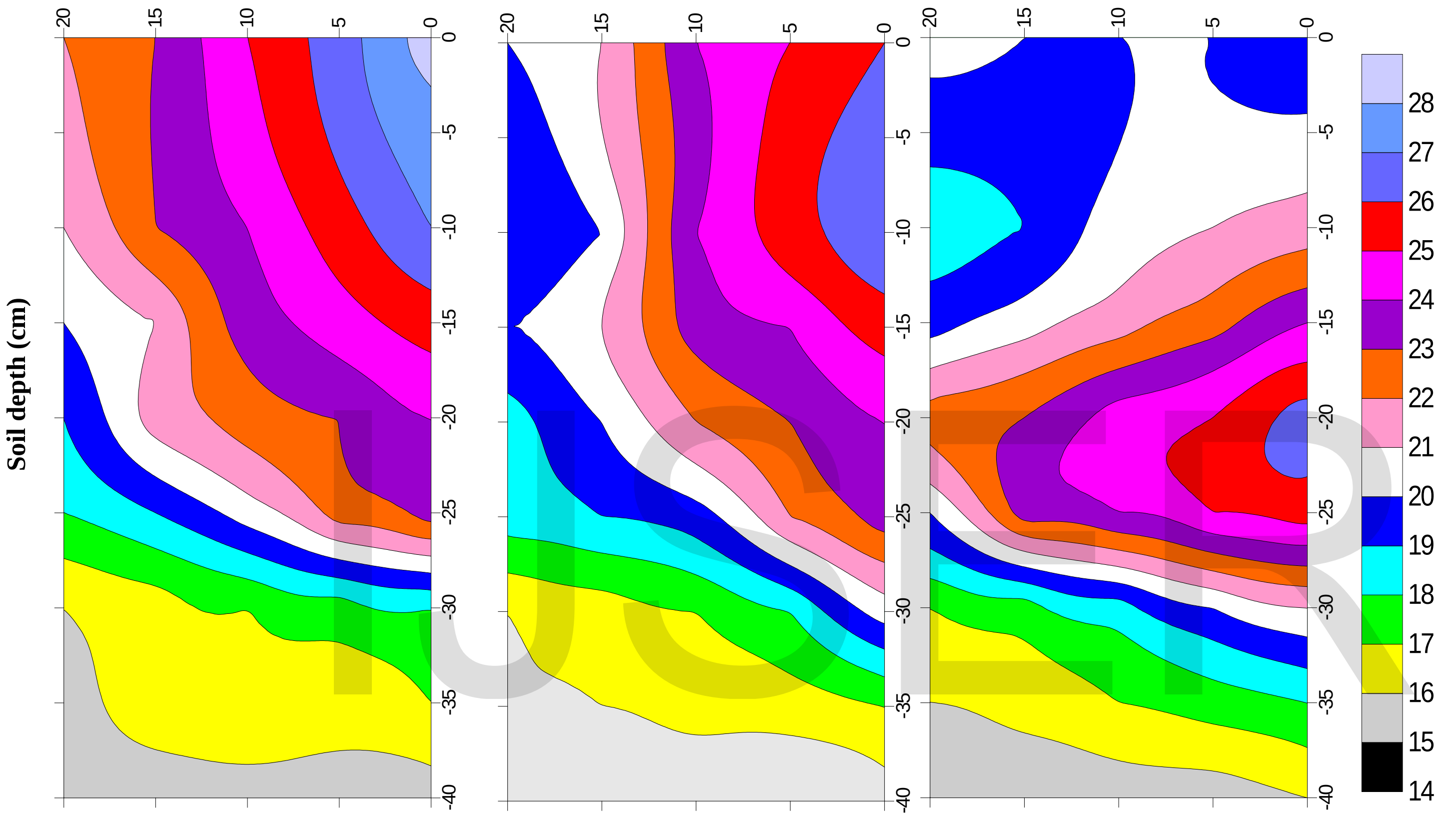
i- Soil-moisture and salts distribution patterns:

Regarding soil moisture distribution patterns, data illustrated in **Figs. (1 and 2)** revealed that irrigation water was speeded on a large volume of soil in the treatment of 20 cm subsurface drip irrigation system followed with 10 cm subsurface drip irrigation one. Water distribution pattern under the treatment of 20 cm subsurface drip irrigation system could be represented with a deficit cone. While under surface drip irrigation one a complete cone was formed with a less volume of soil having readly available water (18% of soil water = 55% of Available water) of onion. Generally, subsurface drip irrigation system give a perfect water distribution in the soil based on the high percent of available water and a great amount of stored water localized at active root zone of onion plant. This finding may be due to upward movement of irrigation water from subsurface emitter plus downward one under the effect of gravitational potential. The obtained results indicated also that, using subsurface emitter buried at 20 cm below soil surface could improve water use efficiency of onion by minimizing the evaporative loss and delivering irrigation water directly to the root zone.

For Salts distribution patterns, Figure (3 and 4) indicated that an accumulation process of leached salts directly under emitter, which occupying from 10 up to 25 cm soil depth, while, it reached to 25 up to 35 soil depth horizontally far from emitter with about 10 cm in vertical direction. Due to leaching process which extended up to 10 cm horizontally far from the emitter from each side. Generally, the treatment of 20-cm emitter depth in subsurface irrigation, introduce best salt distribution and give the low value of soluble salt at active root depth of onion seedlings (0 -25) beside emitter (10 cm horizontally far from emitter). From data analysis it could be concluded that soil salts are accumulated under emitters as a result of salt transported downward. In the case of 10 cm subsurface emitter, capillary action was more pronounced than in 20 cm case because the weakness of capillary action in this soil (coarse textured soil), which have dominance of macro pores

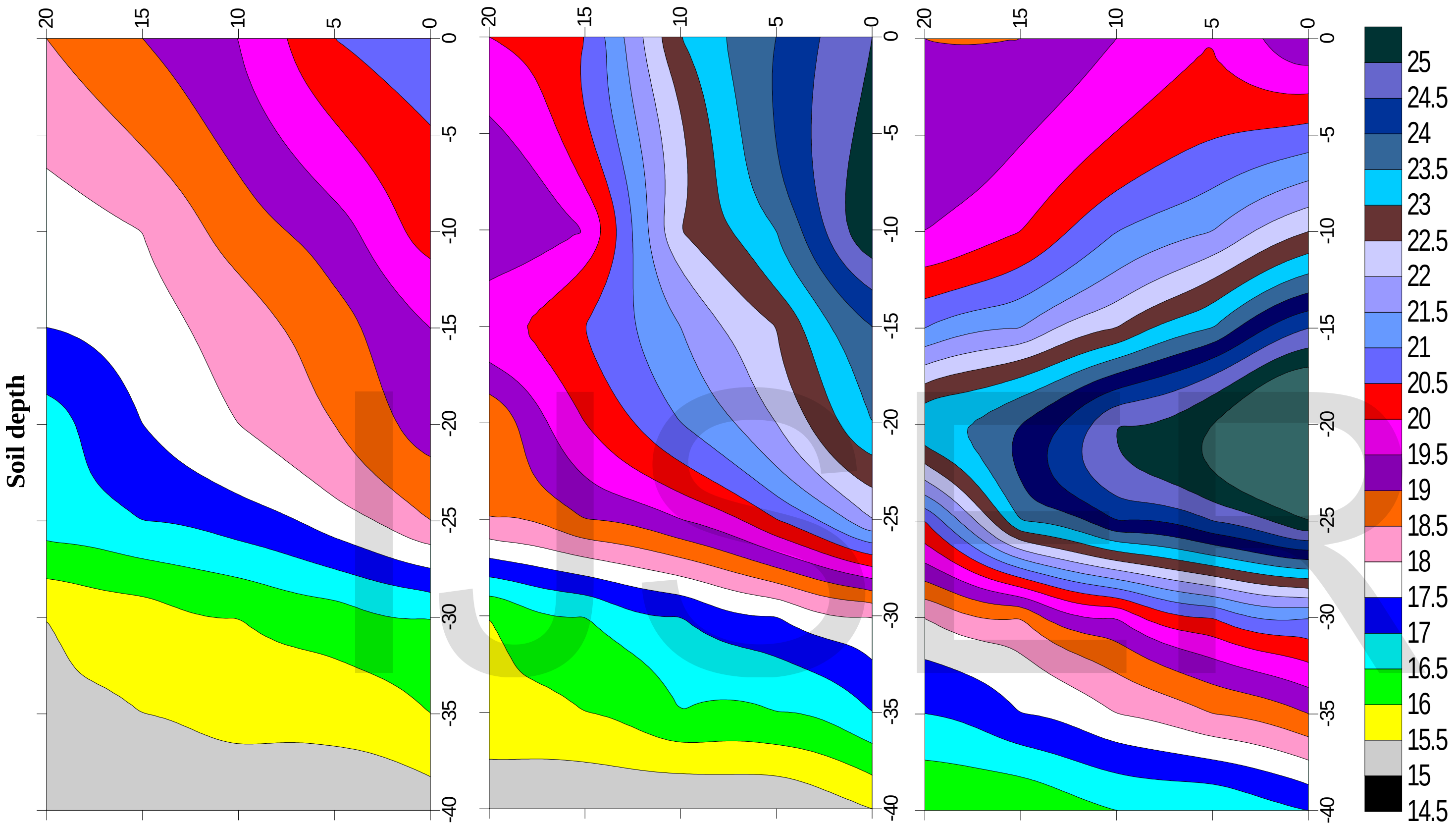
ii. Seasonal values of crop water requirements (SCWR)

Data illustrated in Table (3) showed that the general trend of increasing CWU and attributed SCWR from the beginning of cultivation up to the end of bulb formation stage (72 days after sowing seeds), then it decreasing within bulb enlargement and maturity stage. This is normally observation due to the crop water requirements and the change of micro-climate factors and attributed reference evapotranspiration, as well as, changes of either crop coefficient or crop water stress coefficient. In addition, from data analyses it could be noticed that, the highest values of CWU under developed criteria basis had been reduced compared with traditional way of calculation based on FAO under establishment, vegetative growth, bulb fermentation and bulb enlargement and maturity stages respectively. However, the increment percentage of SCWR had been ranged from 10.55 up to 21.21% under developed criterion comparing with the FAO base calculation method.



(A) (B) (C)

Fig. (1): Water distribution around surface (a) and subsurface (b, c) emitter at 10, 20 cm depth based on developed criteria.



(A) (B) (C)

Fig. (2): Water distribution around surface (a) and subsurface (b, c) emitter at 10, 20 cm depth based on FAO

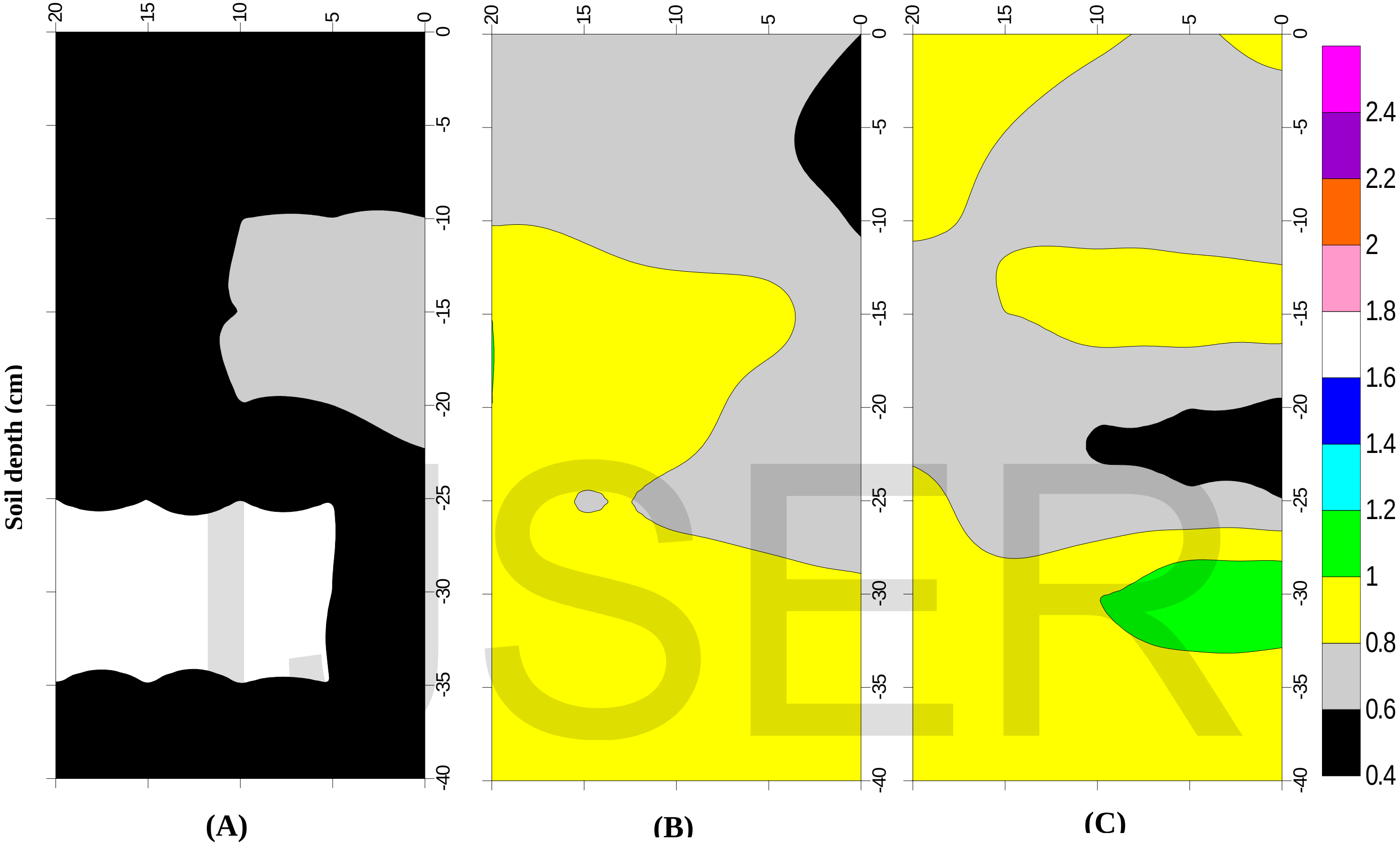
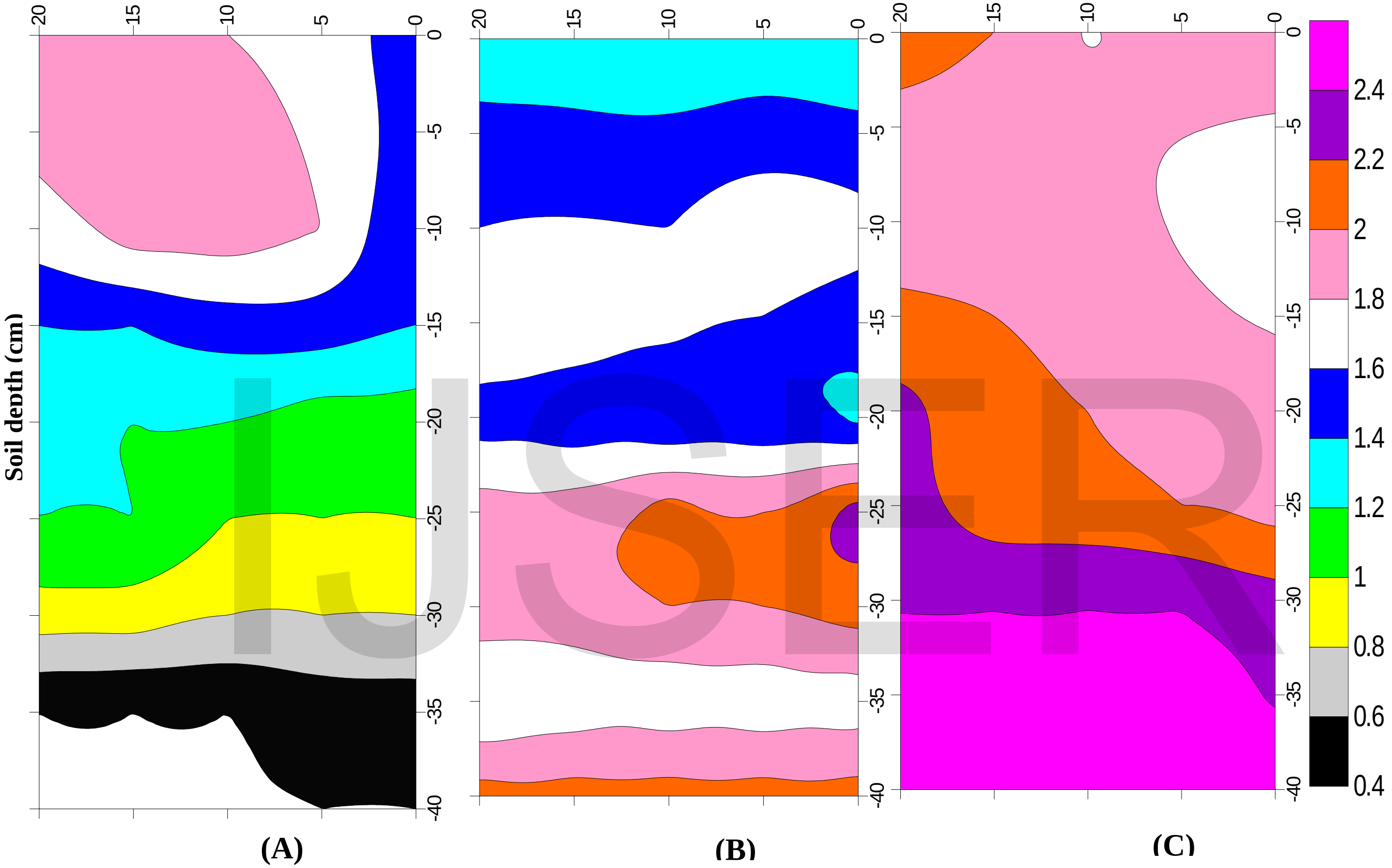


Fig. (3): Salt distribution around surface (a) and subsurface (b, c) emitter at 10, 20 cm depth based on a developed criterion



(A) (B) (C)

Fig. (4): Salt distribution around surface (a) and subsurface (b, c) emitter at 10, 20 cm based on traditional calculation methods of FAO

Table (3): Seasonal Crop water requirements of onion under investigated parameters for the validation process.

Growing season	Drip irrigation system	CWU calculation method	Growing stages / days after sowing seeds													Accumulative CWU, mm/fed	SCWR, m^3/fed		Enhancement percentage, %
			Es(0-16)		Vegetative(17-44)				Bulb formation(45-72)				Bulb enlargement to maturity (73-101)				Leaching requirements (10%), mm	SCWR, mm/fed	
			0-9	10-16	17-23	24-30	31-37	38-44	45-51	52-58	59-65	66-72	73-79	80-87	88-101				
2012-2013	SD	ET_{FAO}	29	12.6	10.08	14.84	18.34	19.04	28	30.66	26.32	23.94	21.28	17.76	24.08	324.64	32.46	1499.8	10.61
		ET_{Eidc}	29	7.56	6.58	13.3	17.78	22.96	23.94	25.48	28.56	23.94	26.32	21.12	20.44	290.20	29.02	1340.7	
	SSD_{10}	ET_{FAO}	25	8.54	8.68	12.88	17.08	21.14	26.32	27.3	26.04	22.4	22.82	22.08	28	315.62	31.56	1458.2	11.20
		ET_{Eidc}	25	6.72	6.3	12.46	16.38	20.72	22.4	25.2	26.74	22.54	27.72	20.48	25.2	280.28	28.03	1294.9	
	SSD_{20}	ET_{FAO}	24	8.96	8.68	14.84	21.84	23.66	29.82	30.66	29.12	25.76	22.82	19.68	28	338.64	33.86	1564.5	21.21
		ET_{Eidc}	24	7.28	8.26	9.38	13.86	20.02	24.5	25.06	28.14	23.24	24.78	17.92	19.04	266.83	26.68	1232.7	
2011-2012	SD	ET_{FAO}	21.78	9.42	7.56	9.26	10.04	10.46	15.38	16.86	19.94	24	21.24	17.76	28.42	250	24.96	1152.9	10.56
		ET_{Eidc}	19.6	5.68	4.94	8.28	9.78	12.6	13.14	14.04	21.64	24	26.28	21.16	24.2	223.20	22.32	1031.2	
	SSD_{10}	ET_{FAO}	16.86	6.42	6.46	8.04	9.38	11.66	14.46	15.02	19.66	22.34	22.8	22.14	33.1	245.11	24.51	1132.4	10.55
		ET_{Eidc}	16.86	5.02	4.72	7.8	8.98	11.38	12.32	13.88	20.2	22.56	27.7	20.44	29.84	219.24	21.92	1012.9	
	SSD_{20}	ET_{FAO}	16.2	6.68	6.56	9.24	12.02	13.04	16.42	16.86	22.02	25.82	22.82	19.68	21.16	245.32	24.53	1133.4	16.11
		ET_{Eidc}	16.2	5.42	6.22	5.86	7.6	11.02	13.46	13.76	21.26	23.3	24.84	17.9	22.5	205.80	20.58	950.8	

REFERENCES:

Alazba, A. A., 2002. Simple mathematical model for water advance determination, **Irrigation Science,** 21: 75-81.

Al-Jamal, M.S.; S. Ball and T.W. Sammis (2001). Comparison of sprinkle, trickle and furrow-irrigation efficiencies for onion production. Agric. Water Manage. 46: 253-266.

Allen, R.G.; Pereira, L.S.; Raes, D. and Smith, M. (1998). Crop evapotranspiration: Guideline for computing crop water requirements. FAO Irrig. Drain. Paper 56: 300.

Arafa, Y. E.; A. M. El-Shazly; H. S. Mehawed and W. K. El-Helew, 2013. Quality characteristics of wheat grains as related to irrigation systems, **3rd Int. Conf. for Agric. And Bio-Engineering: Engineering application for sustainable agricultural development. 23-24 Nov., Ag. Eng. Res. Inst., ARC, Special Issue of Egyptian J. of Ag. Research, 91(2A):** 97-111.

ASABE, 2012. Standards engineering practices data: Design and installation of microirrigation systems (EP405.1-DEC96), 865-869.

Burt, C.M. and S.W. Styles, 1994. Drip and Microirrigation for Trees, Vines, and Row Crops (with Special Sections on Buried Drip). **Irrigation Training and Research Center, Cal Poly, San Luis Obispo, CA,** 261 pp.

Burt, C.M.; A.J. Clemmens; T.S. Strelkoff; K.H. Soloman; R.D. Bliesner; L.A. Hardy; T.A. Howell and D.E. Eisenhauer, 1997. Irrigation performance measures: efficiency and uniformity. **Journal of Irrigation and Drainage Engineering**, 123(6): 423–442.

Clark, G. A.; C. D. Stanley; A. G. Smajstrla and F. S. Zazueta, 1999. Microirrigation design considerations for sandy soil vegetable production systems, **Int. Water and Irrig. J.,** 19: 14-27.

Enciso, J.M.; P.D. Colaizzi and W.L. Multer (2005). Economic analysis of subsurface drip irrigation lateral spacing and installation depth for cotton. **Trans ASAE**, 48(1):197–204.

El-Nemer, M.K., 2014. Adjusted operation time for poor uniformity drip irrigation networks. **Misr J. Ag. Eng.,** 31(3):781-798.

El-Raie, A. E. S. and M. H. Abdel-Wahed, 2005. Comparison of some methods for estimating reference evapotranspiration under Egyptian conditions. **Misr J. Ag. Eng.,** 22(3): 840-860.

Hagag, A. A. and M. A. Mattar, 2005. Water economic return of wheat under pivot irrigation system. **Misr J. Ag. Eng.,** 22(1): 161- 181.

Hanafy, M.; A. M. El-Berry; A. R. Abu-Habsa and B. L. Bishara, 2005. The performance of microtube as an emission point in microirrigation systems. **Misr J. Ag. Eng.,** 22(1): 252-260.

Kamal, H. A. and B. Vencent, 2005. Optimal design of trickle irrigation submain unit dimension. **Misr J. Ag. Eng.,** 22(3): 820-839.

Khalifa, E.M.; M.K. El-Nemer; M.E. Meleha and M.M. Sharaf, 2014. Optimizing amount of applied water for drip irrigation system in North Delta. **Misr J. Ag. Eng.,** 31(3):765-780.

Kumar, S. ; M. Imtiyaz and Ashwani Kumar (2007). Effect of differential soil moisture and nutrient regimes on postharvest attributes of onion (*Allium cepa* L.). Scientia Horticulturae 112 (2007) 121–129.

Mehawed, H.S.; A. M. El-Shazly; and Y. E. Arafa, 2013. Hydraulic assessment of sprinkler types for improving on-farm irrigation efficiencies, **3rd Int. Conf. for Agric. And Bio-Engineering: Engineering application for sustainable agricultural development. 23-24 Nov., Ag. Eng. Res. Inst., ARC, Special Issue of Egyptian J. of Ag. Research, 91(2A):** 367-379.

Slavil, I. and J. Zavadil, 1999. Economical use of irrigation water, **17th ICID Int. Cong. on Irrig. And Drainage: Irrigation water conditions of water scarcity.** Sept. 13-17, Granda, Spain, 231-238.

Steduto, P. and M. Smith, 2000, Water use efficiency, water productivity and biotechnology, **FAO, Rome, Italy**, 10-25.